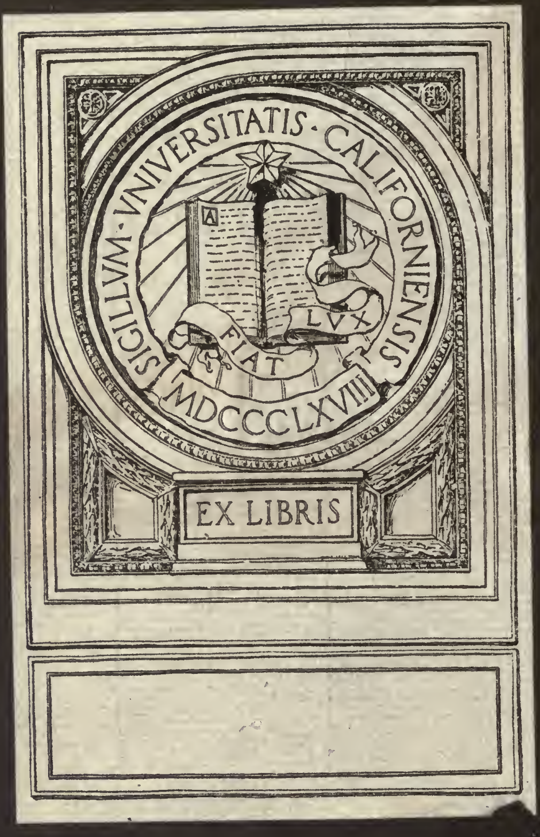
The World's Minerals

With Forty Coloured Plates

L. J. SPENCER, M.A., F.G.S.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THE WORLD'S MINERALS

THE WORLD'S MINERALS

BY

LEONARD J. SPENCER, M.A., F.G.S.
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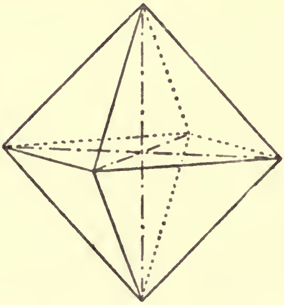
Editor of the Mineralogical Magazine

WITH FORTY COLOURED PLATES



AND TWENTY-ONE DIAGRAMS

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PREFACE.

THE text of this book on minerals is in the main descriptive of the 116 species of the more common simple minerals, which are illustrated by 163 figures on the coloured plates. Descriptions of a few other important species have been added. Technical terms are explained in the preliminary chapters; their use, however, has been avoided as far as possible, and an attempt has been made to present in popular language an interesting and readable account of the several kinds of minerals. Points of general interest are touched upon, and attention is drawn to such of the more prominent characters as will help the student and collector of minerals to identify his own specimens. Mention is also made of the various practical applications of minerals, their importance as ores of the metals, as precious stones, &c.

The forty coloured plates have been prepared under the supervision of Dr Hans Lenk, Professor of Mineralogy and Geology in the University of Erlangen, and many of the pictures represent actual specimens belonging to the mineral collection under his charge.

A correct idea of minerals cannot, however, be conveyed by pictures and descriptions alone. It is necessary to handle actual specimens, and if the student possesses a small collection of his own, his acquaintance with the minerals will be all the more real. There are few objects more attractive and readily preserved, from a collector's point of view, than minerals. Specimens may be acquired for a small sum from the several mineral dealers in London; but if the student can visit mining districts and collect and observe for himself, he will learn far more. A knowledge of minerals is not only of interest in itself, but it can often be turned to useful account.

L. J. S.

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THE WORLD'S MINERALS.

CHAPTER I.

Introduction.

The natural objects found on the surface of our earth, or within its crust at a moderate distance from the surface, may be conveniently classified into three great groups or kingdoms—the animal, vegetable, and mineral kingdoms. The two first embrace everything organic—that is to say, everything that is, or has been, endowed with life; these are largely made up of the chemical element carbon combined with the elements (hydrogen and oxygen) of water. The mineral kingdom, on the other hand, includes all inorganic bodies that have not been produced by the agency of life. Contrasted with materials of organic origin, they show a much greater diversity in the chemical elements that enter into their composition.

A little consideration will show that a comprehensive study of the mineral kingdom is not so simple a matter as might at first sight appear. About a century ago this study was known as mineralogy, but at the present day it is divided up into a number of distinct, though still related, sciences. The geologist studies the wider questions relating to the formation and subsequent destruction of the rocks of the earth's crust; the petrologist determines the different kinds of rocks and their relations to one another; the palæontologist studies the mineralised remains of extinct animals and plants found embedded in rocks; finally, the mineralogist examines the various kinds of simple or individual materials which enter into the composition of the earth's crust, or, as we may say, the A B C of the mineral kingdom. Some other branches of inquiry, such as those relating to ore-deposits, building, ornamental, and precious stones, are also now coming to be studied as more or less special subjects.

It is, of course, not always possible to draw a hard-and-fast line between the animal, vegetable, and mineral kingdoms. To take a simple example: amber is usually treated of as a mineral, and as such finds a place in the present volume; but it is regarded by the botanist as a fossil resin, and it may be of interest to the zoologist also on account of the insects which it encloses. Again, pearls and coral, though consisting of material chemically identical with the minerals aragonite and calcite, and further ranking with the precious stones, are clearly products of the animal kingdom. In such cases there is a certain amount of overlapping; but it is no disadvantage to have the same objects studied from the different points of view of the zoologist, botanist, and mineralogist. These, indeed, are not the only points of view from which such objects may be regarded. The man of commerce looks upon amber, for instance, as valued at so much a pound, and he watches with interest the fluctuations in the supply and demand of the raw material. The practical worker of amber studies each piece with a view to making the most of his available material in fashioning some object of utility. Still again, we may have the legal aspect; and only recently the law courts have been called upon to decide what is amber and what is not amber, and whether china-clay is or is not a mineral.

It would, indeed, be difficult to frame a definition of a mineral which would be satisfactory from every point of view. But as students of nature, it is desirable that we should endeavour to obtain a clear conception of what we may call a simple mineral, or a mineral species.

As examples of mineral substances met with in everyday life, we may mention the following kinds of stones: granite as used for curb-stones, basalt used for macadam roads, marbles used for statuary and the decoration of buildings; many others will at once present themselves to the reader.

If we examine closely a piece of granite, we at once see that it is made up of more than one kind of material; and if we crush it to a coarse powder, we can pick out fragments of three kinds, which to the unaided eye present quite different appearances. These three kinds of material are called quartz, felspar, and mica. If we take them separately and crush them to a still finer powder, each kind would still present exactly the same characters as before; and it is not possible by mechanical means to resolve them into material presenting other characters. It is true that the chemist by analytical methods can still further resolve them into two or more (and in the case of mica as many as a dozen) chemical elements; but by so doing he destroys the original nature of the material and all the characters that appertain to it.

Taking now our next example, that of basalt. To the unaided eye this appears to consist throughout of only one kind of material, or, in other words, it is apparently homogeneous. When, however, a slice is cut so thin that it is transparent, and this is examined under the microscope, it is at once apparent that here also we have a mixture of materials. In the case of marble, on the other hand, we find that this consists entirely of a single kind of material, which is the mineral calcite; and in a white statuary marble the individual crystalline grains of calcite are visible to the unaided eye.

Granite and basalt, therefore, though mineral substances, consist of mixtures of different kinds of minerals. Such mineral mixtures are known as rocks, and the ultimate kinds of minerals of which they are composed are known as simple minerals or mineral species. The term rock may also, for convenience, be applied to marble, since it occurs in nature in very large masses under the same conditions as other rock-masses; if it were found only in small masses it would be merely regarded as a compact variety of the mineral species calcite.

In the following descriptions of the different kinds of minerals—that is, of the various mineral species—we shall find that each species possesses certain essential characters that are always the same, and that these are characteristic of and peculiar to each kind of matter or stuff (*Stoff*, as so expressively used in German).

Before, however, passing to the more detailed description of the species of minerals represented on the coloured plates, it will be necessary to give, at least briefly, some account of the characters of minerals in general (Chapters II.–IV.). Here, also, will be given some explanation of the few technical terms which are employed in the descriptive portion.

CHAPTER II.

The Forms of Minerals.

When minerals grow freely in rock-cavities they assume of their own accord certain external shapes. These forms have the appearance of artificially-made geometrical solids, being bounded by plane surfaces which intersect in straight lines, and they are known as *crystals*. Crystals are, however, not confined to the mineral kingdom, for many other substances, both inorganic and organic, have the power of shaping themselves into such regular forms.

It is quite an easy experiment to cause the growth of crystals of alum, common salt, saltpetre, sugar, &c., by simply dissolving these substances in water and allowing the solution to evaporate. The best method of proceeding is to add to boiling water as much of the substance as will dissolve, and then to pour the concentrated solution into a saucer; as the liquid cools some of the material held in solution will separate out in the form of bright, sparkling crystals on the bottom of the saucer. Larger and better-shaped crystals can be obtained by taking one of those grown in the saucer and suspending it by a thread in a concentrated solution of the same substance; the liquid is then put aside in a room where the temperature is fairly constant, and allowed to evaporate slowly for some days.

Experimenting in this way with different substances that are soluble in water or other liquids, we may get together an interesting and instructive collection of crystals. It will then be recognised that the crystals of different substances are different in shape, each substance, in fact, crystallising in its own fashion or form. Alum, for instance, gives rise to octahedra, common salt to cubes, and sugar to tabular forms of rectangular outline (as in the well-known sugar-candy). Amongst minerals, also, each kind assumes a form of its own; and it is thus possible to distinguish one kind of mineral from another from a consideration of the shapes of their crystals.

The problem is, however, not always an easy one, for there being an almost endless number of minerals and other chemical compounds known to mineralogists and to chemists, so there must be an almost endless variety in crystals. The problem is further complicated by the fact that the crystals of one and the same substance are not always exactly the same in their forms, although these can be reduced to the same type or fundamental form; the common mineral calcite, for example, presents hundreds of different forms of crystals.

It is the business of the crystallographer to study the different kinds of crystals and endeavour to classify the large mass of known facts respecting them. The serious study of crystallography (the science of crystals) dates from the end of the eighteenth century, and during the early part of the nineteenth century the fundamental laws of the science were slowly arrived at by patient study. It has been found that all crystals can be grouped into thirty-two classes, according to the different degree of symmetry they possess; and that these classes fall into seven systems. It is not necessary in this place to give an account of the thirty-two classes of crystals, but the seven systems are of prime importance. The latter may be defined by the relative lengths and angles of inclination of a set of axes of reference, or crystallographic axes, which we are to imagine drawn inside the crystals. It will be convenient (for purposes of reference alone) to give a summary of the seven systems of crystals in this place, and later to explain the matter more fully.

1. **Cubic system**, with three axes, all at right angles to one another, and of equal lengths.

2. **Tetragonal system,** with three axes, all at right angles to one another, two being of equal lengths, and the third either longer or shorter.

3. **Orthorhombic system,** with three axes, all at right angles to one another, and all of unequal lengths.

4. **Monoclinic system,** with two axes inclined to one another, but both at right angles to a third axis, the three axes being of unequal lengths.

5. **Anorthic system,** with three axes, all inclined at oblique angles, and all of unequal lengths.

6. **Rhombohedral system,** with three equal axes, mutually inclined at the same angles, which are not right angles.

7. **Hexagonal system,** with three equal axes, inclined to one another at 60° in one plane, and a fourth axis of different length perpendicular to this plane.

Cubic System.—It will be necessary, to begin with, to explain briefly some of the fundamental principles of crystallography, and for this reason our description of the cubic system will be longer than that of any of the other six systems. Consider a regular octahedron (Fig. 1)—that is, a solid bounded by eight equilateral triangles; by joining the opposite corners we obtain within the solid three lines, AA′, BB′, and CC′, of equal lengths, which intersect at right angles in the centre, O, of the crystal. These three equal rectangular axes are the axes of reference, or crystallographic axes, of the cubic system.

Again, taking a cube (Fig. 2)—that is, a solid bounded by six square planes at right angles to one another in three pairs; by joining the centres of opposite faces we obtain the same set of three equal rectangular axes, which are here parallel to the edges of the cube.

The cube and the octahedron are thus referable to the same set of axes. (In Figs. 1 and 2 the axes are drawn of the same lengths for both solids.) But this is not the only point they have in common; they also possess the same degree of symmetry. From Fig. 1 it is easy to see that the octahedron can be cut along each of the three planes ABA′B′, ACA′C′ BCB′C′ into two equal and similar halves. If one of these halves be placed with its cut surface against a mirror, the mirror-reflection will reproduce the missing half, and the solid will appear complete. These planes, ABA′B′, &c., are known as *planes of symmetry* of the solid. Now a comparison of Figs. 1 and 2 will show that these three planes of symmetry are respectively parallel to the three pairs of parallel faces of the cube; and planes passing through the points bearing the same letters in Fig. 2 will also cut the cube into two equal halves. In addition to these three principal planes of symmetry of the cube and the octahedron, there are in each solid six other planes of symmetry; these can be made out by a little study from the figures, or, better still, with the aid of models.

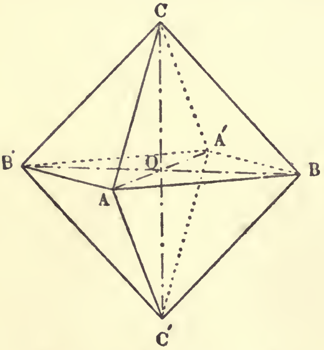

Fig. 1.—The Octahedron, with Axes of Reference.

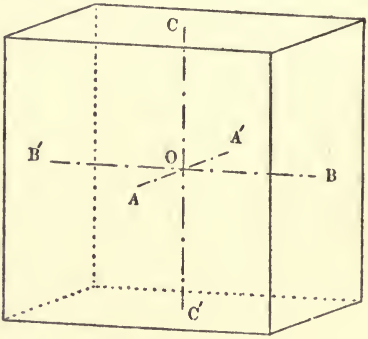

Fig. 2.—The Cube, with Axes of Reference.

Models are, indeed, indispensable aids to the study of crystals, and some of the more simple forms should be made by the reader himself if he wishes to gain much insight into this most interesting subject. Fig. 3 gives the surface of an octahedron unfolded, or developed, in a plane. A tracing of this may be pasted on thin cardboard, cut out, and folded along the dotted lines; the result will be an octahedron. In the same way Fig. 4 will give a cube. When the sheets are folded, the edges of the models may be fixed with gummed paper.

With the aid of the models, it will readily be seen that these solids possess not only nine planes of symmetry, but also a number of *axes of symmetry*. Standing the octahedron up on one corner, C′, and rotating it about the vertical axis, CC′, through a quarter of a complete revolution—that is, so that the point A comes into the position of the point formerly occupied by B—we find that the relative position and aspect of the solid is exactly the same as before; and, further, this covering position is obtained four times during a complete revolution. Such an axis of symmetry is called a tetrad axis of symmetry; and it will be readily seen that, both in the octahedron and the cube, there are three such axes. Both solids also possess four axes of triad symmetry (rotation about which gives three coincident positions during a complete revolution), and six dyad axes (giving only two

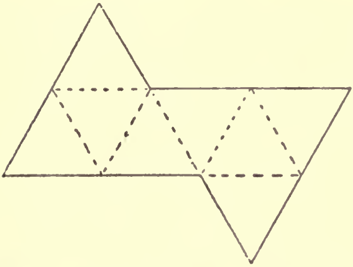

Fig. 3.—Net for the construction of a Model of the Octahedron.

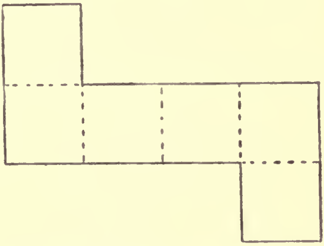

Fig. 4.—Net for the construction of a Model of the Cube.

coincident positions). In addition to these nine planes of symmetry and thirteen axes of symmetry, there is also a centre of symmetry (O in Figs. 1 and 2), through which every point on the solid has a corresponding point reflected at an equal distance on the other side. With the help of his home-made models the student should be able to make out to his own satisfaction all these symmetrical relations of the cube and the octahedron.

We thus see that the cube and the octahedron, though so very different in form, are both referable to the same system of crystals—the cubic system. But these are not the only forms of this system; there are many others.

Studying again Figs. 1 and 2 from a somewhat different point of view, we see that each face of the octahedron intersects all the three axes of reference at equal distances from the centre. The face ABC, for example, cuts the axes at the equal distances OA, OB, and OC. The position of this face, with reference to these axes, is therefore expressed by the symbol (111) (one, one, one). On the other hand, the faces of the cube each intersect only one axis (at the distance OA, OB, or OC), and are each parallel to the other two axes—that is, intersect it at an infinite distance. The position of a face of the cube with reference to the axes is thus expressed by the symbol ($1 \infty \infty$) (one, infinity, infinity), or, if we take the inverse of these, by the symbol (100) (one, naught, naught).

Now let us see what happens if we take a face with the symbol (110)—that is, a face that intersects two axes at equal (unit) lengths and is parallel to the third. We shall find that twelve faces of this kind can be built up around the cubic axes, and the solid we arrive at is known as the rhombic-dodecahedron (Fig. 5), which is bounded by twelve equal rhomb-shaped faces. Continuing our exercise in paper cutting and folding, we shall find that a model (Fig. 6) of this solid possesses all the symmetrical relations of the cube and the octahedron.

Another variation in the intersection of faces on the axes may be introduced by taking fractional lengths on one or two of the axes. Thus a face may intersect two of the axes at the unit length (OA), and the third axis at one-half (or one-third, &c.) this distance from the centre. We shall then derive a more complex form with twenty-four faces, for which the symbol is (112) (or 113, &c.), which is known as an icositetrahedron. Proceeding in this way, we may obtain in the cubic system seven different kinds of simple forms,

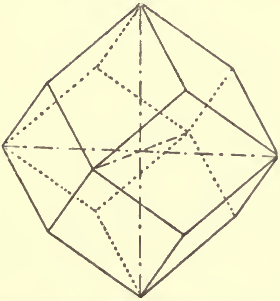

Fig. 5.—The Rhombic-Dodecahedron, with Axes of Reference.

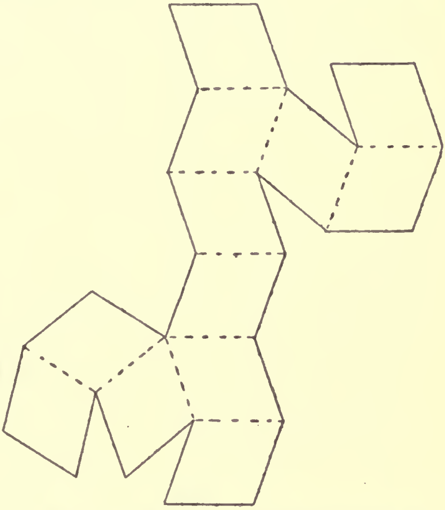

Fig. 6.—Net for the construction of a Model of the Rhombic-Dodecahedron.*

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*A larger model, more convenient for study, may be made by drawing this net on a larger scale; but it is important that the angles of the rhombs should be exactly 70½° and 109½°, and that the edges be all equal.

the most complex being bounded by forty-eight faces, all of which are symmetrically arranged as before.

Now in actual crystals these simple forms may exist either alone or in combination with each other. It may thus happen that one and the same crystal may be bounded by hundreds of small faces; but it will be found that they all obey the definite laws of whole or fractional intercepts on the axes, and that all are arranged with regularity as required by the planes and axes of symmetry noted above.

To give a simple illustration of this combination of forms, we may suppose that the corners of the octahedron are truncated, or chopped off, by faces parallel to the planes AA′BB′, AA′CC′, and BB′CC′—that is, parallel to the faces of the cube; the result will then be as shown in Fig. 7. Or, again, we may truncate the eight corners of the cube by triangular faces parallel to the eight faces of the octahedron (Fig. 9). By increasing the size of the small square faces in Fig. 7, or by increasing the triangular faces in Fig. 9, we arrive at the form shown in Fig. 8, which is known as a cubo-octahedron. These three crystals are therefore essentially the same, differing only in the relative sizes of the faces of the cube and octahedron. The ingenious reader will find instruction in making models of these crystals.

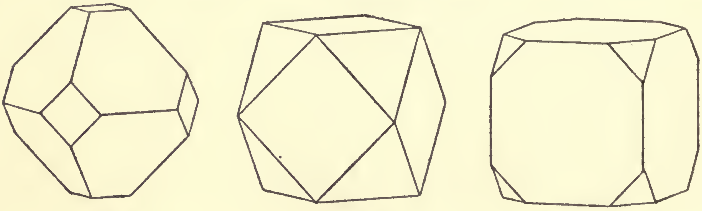

Fig. 7. Fig. 8. Fig. 9.

Crystals consisting of the Cube and the Octahedron in combination.

So far, we have considered crystals to be ideally perfect in their development, but actual crystals as found in nature very frequently display some irregularity or distortion. This irregularity is, however, more apparent than real, and depends only on the relative sizes of the faces and the distances of these from the centre of the crystal. However much a face may be displaced, it always remains parallel to its true position; consequently the angle between two adjacent faces is always the same. This law of the *constancy of angles* is one of the fundamental laws of crystallography.

Any apparent irregularities are due merely to accidents of growth. The crystal may have grown in a cramped position, and material for its growth may not have been supplied to it on all sides at the same rate. Thus the crystals of alum which we caused to grow in a saucer rested on the bottom, and therefore could not grow downwards, but only upwards and sideways; as a result of this, many of these crystals will be of a flattened shape (Fig. 10). When, however, we grow an alum crystal freely suspended in its mother-liquid, material for its growth is supplied equally on all sides, and a crystal of geometrical regularity is formed.

As illustrations of this malformation of crystals, we may give the somewhat extreme cases shown in the accompanying figures (Figs. 10–13). In Fig. 10 we have an octahedron flattened parallel to one pair of opposite and parallel faces; here the material for the growth of the crystal was supplied mainly at the edges, or the crystal may have started its growth in a narrow fissure in solid rock. In Fig. 11 the octahedron has grown more in the direction of an edge between two adjacent faces. Similarly, Figs. 12 and 13 represent distorted forms of the cube. A good example of distortion is shown by the crystals of sodalite in Plate 28, Fig. 1; here six faces of the rhombic-dodecahedron are elongated in the direction of a triad axis to give a form resembling a hexagonal prism.

Although not geometrically perfect, such crystals as these are crystallographically perfect. A comparison of Figs. 10–13 with the perfectly shaped octahedron and cube in Figs. 1 and 2 will show that all the edges between corresponding faces of these crystals retain their true directions, while the angles between corresponding edges and faces are the same. It might be said that these distorted forms are not symmetrical with respect to the planes and axes of symmetry mentioned above; but the symmetrical relations of the angles are preserved, and so is the regularity in the internal structure of the crystal.

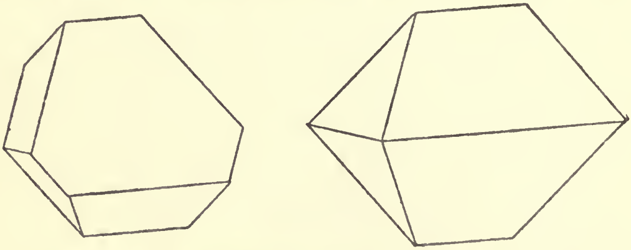

Fig. 10. Fig. 11.

Mis-shapen Octahedra.

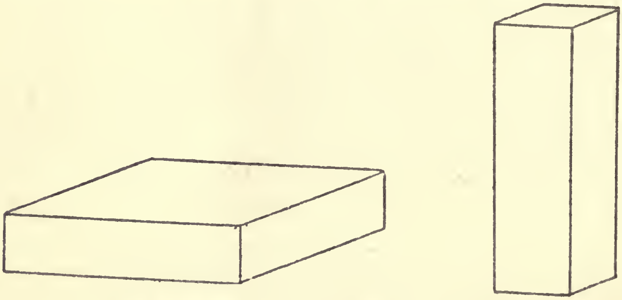

Fig. 12. Fig. 13.

Mis-shapen Cubes.

An important result of this parallelism of the edges of crystals is that their faces are arranged in *zones.* In other words, there is a girdle of faces, the edges of intersection of which are parallel. This is best shown by the nets of the cube (Fig. 4) and the rhombic-dodecahedron (Fig. 6); it will be seen that in the cube there is a continuous strip of four faces, and in the rhombic-dodecahedron one of six faces. Again, in Fig. 7 we see that four octahedron faces and two cube faces lie in a zone, since their edges of intersection are parallel; and on this crystal there are six zones of this kind.

Turning now to the figures on the coloured plates, we shall find many examples from actual mineral specimens of the forms of crystals belonging to the cubic system, of which a brief sketch has been given above.

Minerals that crystallise in the form of the octahedron are illustrated by diamond (Plate 1, Fig. 1) and magnetite (14, 1); those in the cube by native copper (3, 5), iron-pyrites (7, 2), fluor-spar (9, 1 and 2), rock-salt (10, 1 and 2), and perovskite (38, 4). Combinations of the cube and the octahedron are shown by galena (5, 3 and 4) and smaltite (8, 3). The icositetrahedron with the symbol (112) is shown by crystals of analcite (36, 1) and leucite (28, 3), and in combination with the rhombic-dodecahedron by garnet (29, 1 and 2). Other cubic minerals represented on the coloured plates are zinc-blende, tetrahedrite, and sodalite. The special hemihedral forms of iron-pyrites and of zinc-blende and tetrahedrite will be mentioned under these minerals.

Tetragonal System.—Corresponding to the octahedron of the cubic system, we have in the tetragonal system a solid also bounded by eight equal triangles; but here the triangles are isosceles and not equilateral, two of their sides being equal and either longer or shorter than the third. This form is a double pyramid on a square base, and is known as a tetragonal bipyramid (Figs. 14 and 15). In Fig. 14 the vertical axis joining the upper and lower apices of the pyramid is longer than the two (equal) horizontal axes, and we have a steep or acute pyramid. In Fig. 15 the vertical axis is shorter, and the pyramid is low or obtuse.

Here, then, we see that there may be a variation in the angle between the faces of the crystal. In the cubic system the angles of the octahedron are, of course, always the same whatever be the mineral crystallising in this form. In the tetragonal system, on the other hand, the angle between the faces of the pyramid will be different for different minerals, but it will always be the same for the same kind of mineral. The particular value of this angle (from which can be calculated the ratio or relative lengths of the vertical and horizontal axes) is fixed for, and characteristic of, each kind of mineral. Other pyramids may, however, be present if

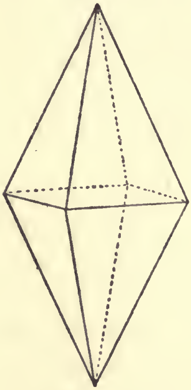

Fig. 14.

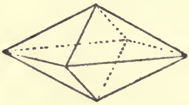

Fig. 15.

Tetragonal Bipyramids.*

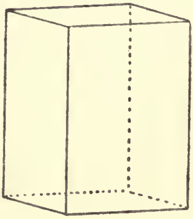

Fig. 16.

Tetragonal Prism with Basal Planes.

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* In Fig 14 the vertical axis has been made twice the length of the equal horizontal axes; and in Fig 15 it is half the length of the latter.

they intersect the unit vertical axis in simple multiple or sub-multiple distances; and in this way we may have a combination of steep and low pyramids on the same crystal.

Suppose that the pyramid faces become so steeply inclined that they intersect the vertical axis at an infinite distance, we should then have four faces parallel to this axis, and so obtain a square prism. Again, we may imagine the pyramid to become flatter and flatter until finally its four upper faces and its four lower faces coincide in one plane or pair of parallel planes. We then have a form of the tetragonal system known as the basal plane, or, taking the two parallel planes together, as the basal pinacoid. Neither of these forms—the square prism and the basal pinacoid—completely encloses space, so that in crystals they can exist only in combination with other forms. Fig. 16, for instance, is a combination of these two simple forms, the ends of the tetragonal prism being closed by the pair of parallel faces of the basal pinacoid.

Tetragonal crystals are represented on the coloured plates by scheelite (Plate 22, Fig. 4) in simple tetragonal bipyramids; wulfenite (22, 3) and cuprouranite (24, 3) in flat square plates with a large development of the basal pinacoid. Combinations of two tetragonal prisms with a pyramid are shown by zircon (14, 4) and idocrase (29, 4), the latter showing also the basal plane. Other tetragonal minerals here represented are copper-pyrites (8, 1 and 2) and cassiterite (14, 3).

Orthorhombic System.—Here, again, the primary form is a solid bounded by eight equal triangles, but now the edges of the triangles are all unequal. This form is called a rhombic bipyramid (Fig. 17), since the three sections of it made by planes, each passing through four of its corners, are all rhombs. These three planes each cut the solid into two equal and similar halves, and they are therefore planes of symmetry (corresponding to the planes ABA′B′, ACA′C′, and BCB′C′ of the regular octahedron). In the orthorhombic system these are the only possible planes of symmetry. Other simple forms are rhombic prisms and pinacoids. The prisms consist of four faces parallel to one or other of the three axes, and they have a rhomb-shaped cross-section. The three pinacoids each consist of a pair of faces parallel to two of the axes. Fig. 18 shows a rhombic prism parallel to the axis BB′, its ends being closed by the pinacoid parallel to the axes AA′ and CC′.

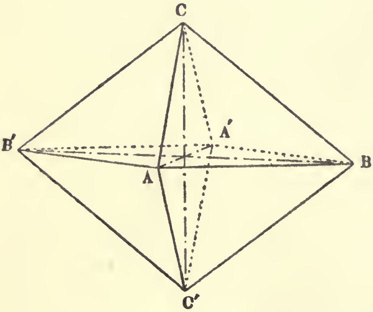

Fig. 17.
Rhombic Bipyramid.

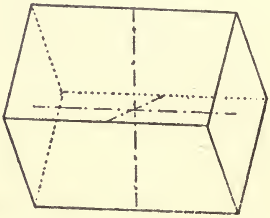

Fig. 18.
Rhombic Prism with Pinacoid.

From the angles between the faces of the crystals it is possible to calculate the relative lengths of the three unequal axes AA′, BB′, and CC′. These values are different for different minerals, but constant for crystals of the same mineral.

Many minerals crystallise in this system; on the coloured plates examples are shown of orthorhombic crystals of sulphur, mispickel, marcasite, atacamite, manganite, cerussite, aragonite, barytes, anglesite, celestite, olivine, topaz, andalusite, staurolite, and columbite.

Monoclinic System.—Here we have an oblique angle between two of the three axes, and this system is consequently often known as the oblique system. The crystals possess only one plane of symmetry, as may be seen from the figures of gypsum (Plate 21, Fig. 1) and augite (27, 1). The simple forms consist of no more than two or four faces, which of themselves cannot enclose space; so that all crystals of this system consist of two or more simple forms in combination. The crystals of lazulite shown in Plate 24, Fig. 2, consist of a combination of two monoclinic hemi-pyramids; and here, since the oblique angle does not differ much from 90°, the combined form has quite the appearance of a rhombic pyramid.

Other common minerals crystallising in this system are wolframite, orthoclase, hornblende, diopside, epidote, muscovite, zinnwaldite, clinochlore, and sphene, all of which are represented on the plates.

Anorthic System.—Here not only are all the axes of unequal lengths, but they are all inclined at oblique angles. There are no planes or axes of symmetry, but only a centre of symmetry. Each simple form, therefore, consists only of a pair of parallel faces, and a complete crystal must be bounded by at least three such forms.

Examples are given by microcline, anorthite, kyanite, and axinite.

Rhombohedral System.—In this system the typical or primary form is a rhombohedron—that is, a solid bounded by six equal rhomb-shaped faces. This form possesses a certain resemblance to the cube. If we stand a cube up on one corner with one of its four triad axes (p. 9) in a vertical position, and imagine the solid to be drawn out or compressed along this direction, we obtain a rhombohedron. An acute rhombohedron so produced by the elongation of a cube is shown in Fig. 19, and an obtuse rhombohedron formed by the compression of a cube along the triad axis is shown in Fig. 20. These forms exhibit a three-fold arrangement of their faces about the vertical axis, which is thus an axis of triad symmetry, corresponding to one of the triad axes of the cube. There are also three vertical planes of symmetry, each perpendicular to a face of the rhombohedron, and coinciding with an edge. All the edges of an ideally developed rhombohedron are equal in length and are equally inclined to the vertical axis; and these are the lines which in this system of crystals are taken as the axes of reference.

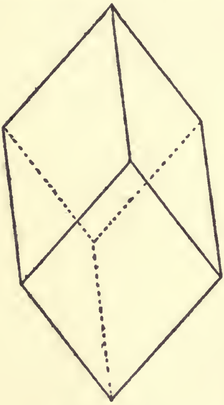

Fig. 19.
Acute Rhombohedron.

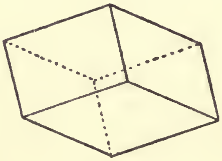

Fig. 20.
Obtuse Rhombohedron.

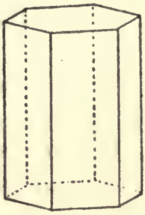

Fig. 21.
Hexagonal Prism
with Basal Planes.

If we imagine a rhombohedron to be enormously elongated in the direction of the vertical axis, its six faces will eventually become parallel to this axis, and a hexagonal prism will result. If, on the other hand, the rhombohedron be compressed in the same direction, the limiting form will consist of a pair of faces perpendicular to the vertical axis; this form is then known as the basal pinacoid. Fig. 21 shows a combination of a hexagonal prism and the basal pinacoid.

Another simple form of importance in the rhombohedral system is that known as the scalenohedron; this is a solid bounded by twelve scalene triangles, and still showing a three-fold arrangement about the vertical axis.

Simple rhombohedra are shown by the minerals calcite (Plate 16, Figs. 2 and 3), rhodochrosite (17, 3), chalybite (5, 3), and chabazite (36, 2); and in combination with other forms by pyrargyrite, proustite, quartz, hæmatite, corundum, and tourmaline.

Hexagonal System.—This system has many points in common with the rhombohedral system, but instead of showing a three-fold arrangement of faces about the vertical axis, there is a six-fold arrangement. In the crystals of apatite, pyromorphite, vanadinite, and beryl illustrated on the coloured plates, the only forms present are the hexagonal prism and the basal pinacoid, exactly as in **Fig. 21** of the rhombohedral system. In some crystals, however, especially those of beryl and apatite, many more faces are sometimes present.

The Habit of Crystals.—Apart from the actual degree of symmetry which they possess and the system to which they belong, crystals very often present a certain kind of development or 'habit,' and this may often be a characteristic feature of some minerals. Differences in habit result from the unequal development of the different forms or faces of the crystals. The prism faces, for instance, may be greatly extended, and we then have a columnar crystal, which is said to be prismatic in habit, as in crystals of beryl (Plate 28, Fig. 4), aragonite (28, 4), andalusite (31, 1 and 3), tourmaline (33, 1), &c. If the prisms are relatively longer and thinner, the habit may be described as long-prismatic, or rod-like; as in stibnite (4, 2), actinolite (26, 2), epidote (32, 1), &c. When the prisms are still thinner, the habit becomes acicular or needle-like; as in crocoite (22, 1). In some crystals the prisms may be so very long and slender that the habit is capillary, or hair-like; this is an extremely characteristic habit of the mineral millerite (sulphide of nickel), which on this account is sometimes known as 'hair-pyrites.'

If, on the other hand, the prism faces be short and the basal plane largely developed, the crystal will be plate-like, or tabular, in habit. Examples of this are shown by barytes (Plate 20, Fig. 1), wulfenite (22, 3), the micas (34, 1–3), and chlorites (34, 4). This tabular habit is especially characteristic of the micas, the crystals of which often have the form of small scales. A pyramidal habit is usually shown by native sulphur (1, 3), scheelite (22, 4), &c. Rock-salt (10, 1 and 2) and fluor-spar (9, 1 and 2) are characterised by their cubic habit, whilst diamond (1, 1) and magnetite (14, 1) most frequently exhibit an octahedral habit; octahedra of rock-salt and fluor-spar and cubes of diamond and magnetite are, however, sometimes found.

Intergrowths of Crystals.—Intergrowths of two or more crystals are of frequent occurrence. Two crystals which commenced their growth at neighbouring centres would in time fill up the intervening space; they would then coalesce and hinder each other's growth. The two individuals, having commenced their growth quite independently, would naturally not be related to one another in any definite manner, and their relative positions would be quite accidental. Examples of irregular intergrowths of this kind are to be seen on almost all of the accompanying plates. Sometimes, however, there may be a parallel grouping of the individual crystals; as shown, for example, by barytes in Plate 20, Fig. 2, and celestite in Fig. 4 of the same plate.

In certain cases, however, the two individuals are grown together in a certain definite and regular manner, as if one were the mirror-reflection of the other. Such a grouping is called a twinned crystal, or a *twin*, and the plane of reflection is called the twin-plane. One portion of the twin can be brought into a position identical with that of the other portion by a rotation of half a revolution (180°) about an axis perpendicular to the twin-plane. Twinned crystals usually show re-entrant angles between the faces of the two individuals, and very often this is erroneously taken as an indication of the presence of twinning; but it must be remembered that in any accidental or parallel intergrowth of two crystals there would also be re-entrant angles between the faces.

A few good examples of twinned crystals are shown on the coloured plates. The cross of staurolite (Plate 33, Fig. 5) clearly shows the intergrowth of two prismatic crystals almost at right angles to one another. In Plate 21, Fig. 2, is shown a 'swallow-tail' twin of the gypsum. Plate 9, Fig. 1, shows interpenetrating twinned cubes of fluor-spar with the corners of smaller cubes projecting from the faces of larger cubes; and Plate 36, Fig. 2, very similar groups of chabazite, but here the crystals are rhombohedra with very nearly the shape of cubes. Knee-shaped twins of cassiterite are shown in Plate 14, Fig. 3; and in marcasite (Plate 7, Fig. 1) five orthorhombic crystals are twinned together to produce a pentagonal form. The pseudo-hexagonal prisms of aragonite (Plate 18, Fig. 3) are also the result of the twinning together of several orthorhombic crystals.

Forms of Aggregation of Crystals.—Many minerals, instead of growing as single and distinctly developed crystals, give rise to various, more or less, accidental shapes and various kinds of structure or texture, due to the crowding together of a large number of crystal individuals. Although this, of course, complicates the study of the crystals themselves, yet these forms of aggregation are often extremely characteristic of particular minerals.

When the material consists of a vast number of minute crystalline individuals closely crowded together, and each individual is developed to approximately the same extent in all directions, we have a granular crystalline structure. Here the crystallisation of the material had clearly started simultaneously at a large number of neighbouring centres, and all the intervening spaces soon became filled up, forming a mass of crystalline grains, but without the development of any crystal faces. Such a structure is well shown by statuary marble and by loaf-sugar; on fractured surfaces of these materials the extent of each crystalline individual forming the mass is readily seen when the bright cleavage surfaces are examined with a magnifying-glass. If the crystalline grains are so small that they cannot be distinguished, except under the high powers of a microscope, the structure is described as compact, and the mineral is said to be massive. Examples of this are shown on the coloured plates by jasper (Plate 12, Figs. 2 and 3), hornstone (12, 4), pitchblende (14, 5), turquoise (24, 5), nephrite (26, 4), lapis-lazuli (28, 2), serpentine (35, 1), and meerschaum (35, 2). Masses of these minerals will, of course, show no external crystalline form; and if they present any external surface, other than that of fracture, this will, as a rule, be rounded, or nodular.

A different kind of structure results when the individual crystals of the aggregate are greatly elongated in one direction. If the crystals are of an appreciable size, the structure may be said to be columnar, while if they are finer the structure is described as fibrous. Now, we may have different kinds of fibrous structure, according to the manner in which the fibres are arranged in the aggregate. They may have a parallel arrangement, as in cerussite (Plate 18, Fig. 4), gypsum (21, 3), and crocidolite (26, 3). When the fibres are very fine this parallel fibrous structure gives rise to a silky lustre in the mineral, as is to be seen in the satin-spar variety of gypsum and in crocidolite. Again, the fibres may be matted together to produce a felt-like aggregate; as in the mineral known as 'mountain-leather,' or 'mountain-cork.' Or, again, they may radiate from a centre, producing star-like groups. The last form of aggregation is especially common amongst minerals, and may be of different degrees of coarseness or fineness; for example, in tourmaline (Plate 33, Fig. 3), chessylite (19, 1), stibnite (4, 1), pyrolusite (15, 2), wavellite (24, 1), natrolite (37, 1 and 2), &c.

Very often minerals with a radially fibrous structure present on their free surfaces a rounded form. Many varieties of such external rounded forms may be distinguished, and these are sometimes quite characteristic of certain minerals. A globular or hemispherical form is invariably shown by wavellite (Plate 24, Fig. 1; here the hemispherical aggregates have been broken across). Nodules of hæmatite are very often kidney-shaped, or reniform (13, 2). In the mineral prehnite the rounded forms are themselves often aggregated like a bunch of grapes, and on this account this form of aggregation is described as botryoidal. Mamillary or breast-like surfaces are shown by malachite (19, 4) and native arsenic (2, 1). Combined with a radially fibrous structure, there may also be a concentric shelly structure, as shown by malachite (19, 4) and aragonite (18, 2). In the last instance the concentric shelly structure predominates; and a number of the pea-like forms are themselves aggregated to give a pisolitic structure.

Again, we may have a radial arrangement of fibres, not about a point, but around a line or axis; and the external form may then be stalactitic (e.g. psilomelane, 15, 4), or coralloidal (e.g. aragonite, 18, 1). Such a coralloidal form is especially characteristic of the variety of aragonite known as flos-ferri.

Many other forms of aggregates might be mentioned—for example, mossy, leafy, wiry (native silver, Plate 2, Fig. 5), dendritic or tree-like (wollastonite, 27, 6). The amygdaloidal or almond-like form so characteristic of agates (12, 1) arises from the mineral filling a rock-cavity of this shape.

Amorphous Minerals.—There are but few minerals that possess no indications of crystalline structure. These are of the nature of glasses, or colloids; and the best example is afforded by opal (Plate 16, Figs. 4 and 5). Such minerals present a smooth and glassy fracture, and usually occur as fillings in rock-cavities; sometimes, however, they may present rounded or botryoidal external surfaces.

Pseudomorphs.—When a mineral, still in the earth's crust, is exposed to conditions other than those that prevailed at the time of its origin and growth, it may happen that these will lead to its destruction. The crystals may be re-dissolved, and their material carried away in solution to be deposited elsewhere; or chemical changes may take place and a new generation of minerals be produced. There are thus in the inorganic world, just as in the organic, periods of growth and decay, and minerals are by no means so permanent as might be imagined.

A crystal of iron-pyrites (sulphide of iron) embedded in the solid rock may at last be attacked by percolating surface waters containing oxygen in solution; its sulphur would be removed as sulphuric acid or as calcium sulphate, while the iron would be oxidised and take up water, so giving rise to a new growth of the mineral limonite (hydroxide of iron). The space formerly occupied by the cube of iron-pyrites is now taken up by limonite, a mineral which never crystallises as cubes, or indeed in any other form. We have then a pseudomorph (or false form) of limonite after iron-pyrites.

CHAPTER III.

The Physical Characters of Minerals.

The physical characters of minerals afford many extremely interesting subjects for study, but here we can touch on only a few of the more important points. Of especial interest is the fact that in crystals many of the physical characters vary with the direction within the crystal. For instance, light travels through a crystal with different velocities according to the direction of transmission; in other words, a ray of light can travel more quickly along some paths within a crystal than along others. The action of crystals on light presents many problems of extreme complexity, which can be studied only with the aid of special instruments. Nevertheless, the colour of minerals and of their crystals is a character that first attracts attention; so that this part, at least, of the subject must be dealt with here.

Colours of Minerals.—The colours of some minerals are so well known that they are used as descriptive terms in defining colour; for instance, we speak of gold-yellow or golden, silver-white, emerald-green, ruby-red, sapphire-blue, &c. It would, indeed, be possible to draw up a complete nomenclature of colours by comparison with minerals, for these exhibit every possible range of colour. The recognition of minerals by their colour alone is, however, very uncertain, and a wide experience is necessary before such a knowledge can be of much practical value.

Many species of minerals may themselves exhibit a wide range of colour, so that one and the same kind of mineral may be very different in its appearance in this respect. For instance, the popular idea of topaz is a gem-stone of a sherry-yellow colour; but when quite pure and free from colouring matter this stone is perfectly colourless and water-clear; or again, it may be pink, bluish, or greenish. In the same way, the mineral corundum is colourless when quite pure; but other crystals may range through all the colours of the rainbow—red (ruby), orange, yellow ('oriental topaz'), green ('oriental emerald'), blue (sapphire), and violet ('oriental amethyst'), and when larger amounts of impurities are present we have the black emery; all these are colour-varieties of one and the same kind of mineral. Quartz, fluor-spar, and many other minerals show similar ranges of colour.

In the instances just mentioned the crystals are transparent and clear, and they owe their colour to the presence of very small amounts—often mere traces—of colouring matter diffused through the substance itself in much the same way that a dye is dissolved in water.

In other cases we may have a colourless crystal coloured by the inclusion of particles of other minerals, which may be very minute, and present in such considerable numbers as to make the crystal opaque. A good instance of this is given by ferruginous quartz (or 'Eisenkiesel') and jasper, which owe their yellow and red colours to the presence of yellow and red oxides of iron in relatively large amounts.

In the two cases so far mentioned the colour shown by the crystals is not the colour of the pure mineral—which of itself is often white or colourless—but is due to the presence of some colouring matter. The true colour may be determined by crushing a fragment of the mineral on a sheet of white paper, or by rubbing a piece on unglazed porcelain. This is known as the *streak* of the mineral, and the colour of the streak is a much more definite character of a mineral than the colour seen in bulk.

Other minerals possess a colour of their own, and for these the colour of the streak is the same, or nearly the same, as the colour shown by the mineral in bulk. The colours of gold and copper, for instance, are inherent in these substances; it is, however, to be remembered that native gold may be paler in colour when alloyed with much silver, and that native copper is often black or green on the surface, owing to alteration. Cinnabar (Plate 6, Figs. 2 and 3), orpiment (4, 3), malachite (19, 3 and 4), and chessylite (19, 1 and 2), again, are minerals with colours of their own, respectively red, yellow, green, and blue, which are the same also in the streaks. The different ores of iron can be readily distinguished by the colours of their streaks; that of magnetite is black, hæmatite red, limonite brown, and chalybite white.

The colours displayed by some minerals are of a totally different nature; they are not in the minerals themselves, but are produced by the action of certain structures in the mineral on white light. The different coloured rays of which white light is composed are acted upon in such a way that certain colours are eliminated, while others remain as flashing rainbow colours. The interference-colours so produced by precious opal and labradorite are of the same nature as those shown by a soap-bubble or by a film of oil on water. Of the same nature also are the iridescent colours shown by the tarnished surfaces of some minerals, or reflected from cracks in the interior of crystals.

Still another colour effect of crystals, which may be mentioned here, is that known as *pleochroism* or dichroism. Many coloured crystals are of a different colour according to the direction through which they are viewed. A crystal of the mineral cordierite (or dichroite), for instance, is dark-blue, light-blue, or straw-yellow when viewed through in three directions at right angles. This character, which can be most conveniently examined with a little instrument called a dichroscope, affords a ready means of distinguishing many kinds of coloured gem-stones.

Transparency and Lustre.—Some minerals are always opaque, as, for example, the metals and most of the metallic ores. Others—e.g. quartz—may vary from perfect transparency to complete opacity, an intermediate degree being described as translucency; but in such cases the specimens which are opaque in the mass will show light through the edges of thin splinters.

The lustre of minerals varies not only in intensity, but also in kind, and the kind of lustre is often a very characteristic feature of different minerals. The metallic lustre of metals and many metallic ores is, for instance, quite different in character from the glassy (or vitreous) lustre of quartz; and the peculiar adamantine lustre of diamond enables this mineral to be recognised at a glance. The lustre of other minerals may be waxy, greasy, resinous, silky, &c.

The physical characters so far enumerated depend on the action of crystals on light. On the other hand, some minerals are themselves acted upon by light; on exposure they may lose their colour, transparency, and lustre. A striking instance of this is afforded by the mineral proustite (Plate 8, Fig. 6), which is ruby-red, transparent, and has a brilliant adamantine lustre; but on exposure to light it soon becomes black, opaque, and dull. The transparent, aurora-red crystals of realgar (Plate 4, Fig. 4) soon fall to a yellow powder when exposed to light. In collections, such minerals must, therefore, be protected from the light.

Specific Gravity.—After colour and lustre, the character which next attracts attention is that of heaviness. It is soon noticed that some minerals are heavier than others, and in this respect there are indeed very wide differences. The extremes of specific gravity range from 1·05 in amber to 23 in iridium; that is, amber is only slightly heavier than an equal volume of water, while iridium is twenty-three times as heavy. The following table illustrates how various common minerals differ in their specific gravity.

Amber	1·05	Jadeite	3·33	Cassiterite	7·0
Borax	1·7	Diamond	3·52	Galena	7·5
Sulphur	2·1	Chessylite	3·8	Cinnabar	8·1
Rock-salt	2·15	Corundum	4·0	Copper	8·85
Gypsum	2·3	Barytes	4·5	Bismuth	9·75
Orthoclase	2·56	Pyrolusite	4·8	Silver	10·6
Quartz	2·65	Iron-pyrites	5·0	Lead	11·4
Calcite	2·72	Arsenic	5·7	Mercury	13·6
Muscovite	2·9	Mispickel	6·0	Platinum	17·0
Fluor-spar	3·2	Cerussite	6·5	Gold	19·0

The specific gravity can be determined with accuracy, and its value expressed in definite numbers; and being different for different minerals, it is an extremely valuable character of determinative value. With a little practice, it is possible by simply handling a specimen to gain some idea of the approximate value of its specific gravity, and so to distinguish between minerals which may be alike in general appearance.

The methods available for the accurate determination of this most important character are explained in the text-books on physics; they depend on the principle of determining the weight of water displaced by the body, and so finding the ratio between the weight of the body and the weight of an equal volume of water. A specially quick and ready method, particularly suitable for determining the specific gravity of minerals, is that given by the use of heavy liquids. The liquid compound methylene iodide has a specific gravity of 3·33 (i.e. it is more than three times heavier than water), and is miscible in all proportions with benzole (sp. gr. 0·89). A cheaper * heavy liquid is bromoform, with the lower specific gravity of 2·8.

* Methylene iodide costs 3s. 6d. per ounce, and bromoform 8d. per ounce. Methylene iodide darkens on exposure to light, and it should therefore be kept covered up; any depth of colour it may acquire can be removed by allowing bits of metallic copper to remain in the liquid.

If fragments of the minerals named in the above table of specific gravities be dropped into methylene iodide, fluor-spar and all those of lower specific gravity will float on the surface of the liquid, whilst diamond and all of higher specific gravity will sink to the bottom; jadeite, with a specific gravity exactly the same as that of the liquid, will, however, remain suspended in the liquid, neither floating nor sinking. By the addition of benzole to the methylene iodide the specific gravity of the liquid may be reduced to any desired amount; so that any of the lighter minerals will remain suspended.

Selecting a series of known minerals of known specific gravity for use as indicators in the heavy fluid, we shall, by comparison, be able to determine the specific gravity of a fragment of an unknown mineral, and this will be of great assistance in determining the kind of mineral. This, of course, can only be done when the specific gravity of the mineral is less than 3·33; but still, it is often of great help to learn that the specific gravity of an unknown mineral is greater than this. For instance, faceted gem-stones of similar appearance can often be readily distinguished by simply dropping them into the heavy liquid. Thus, if we wish to distinguish between quartz (sp. gr. 2·65) and topaz (sp. gr. 3·5), it will at once be seen that the former floats and the latter sinks.

The Fracture and Cleavage of Minerals. — When minerals or crystals are broken their surfaces of fracture present many points of difference, and these differences are important aids in distinguishing minerals of different kinds. The crystals of some minerals possess a special kind of fracture known as *cleavage*, it being possible to split or cleave them along plane surfaces parallel to certain faces of the crystal. Thus crystals of rock-salt or galena, whether they be cubes or of any other form, can be readily split parallel to the faces of the cube. Cubes of fluor-spar cannot be split in these directions, but only parallel to the faces of the octahedron. Diamond also possesses a perfect octahedral cleavage, while zinc-blende cleaves parallel to the faces of the rhombic-dodecahedron. These cleavages may be developed parallel not only to one face of these simple forms, but parallel to all; since the internal crystalline structure of the material possesses the same degree of symmetry as the external form of the crystal. Thus, since a cube is bounded by three pairs of parallel equivalent faces, there must be in rock-salt and galena three directions of cleavage at right angles to one another. In the same way, fluor-spar and diamond each have four directions of cleavage parallel to the four pairs of parallel faces of the octahedron; and in zinc-blende there are six.

In calcite there are three directions of perfect cleavage parallel to the three pairs of parallel faces of the primary rhombohedron. In crystals belonging to crystal-systems other than the cubic, there may be only one plane direction of cleavage, since there can be no symmetrical repetition of this direction within the crystal. Thus the micas possess one very perfect cleavage parallel to the basal plane, and gypsum one parallel to the single plane of symmetry.

The cleavage of a crystal is an expression of a minimum of cohesion in a certain direction in the material of the crystal; and it is important to remember that the crystal can be split up indefinitely along its direction of cleavage. Taking, for example, a crystal of mica, we can keep splitting off thin leaves until the whole crystal is separated into flakes, and these flakes can still further be subdivided with a knife-edge along the same direction of cleavage. With the harder minerals the best way of producing the cleavage is to place a knife-edge on the crystal parallel to the particular crystal-face, and to strike the back of the knife with a sharp blow from a hammer.

The cleavages of minerals differ not only in direction and the number of directions, but also in their perfection. Some minerals cleave more readily than others, and their surfaces of separation are much smoother and brighter. In other minerals the cleavage may be so poor that it is scarcely noticeable. Here the kind of *fracture* is often of importance. Quartz and opal, for example, break with a smooth and glassy conchoidal fracture, the surfaces being rounded and having curved lines like the lines of growth on the surface of a bivalve shell. Other kinds of fracture are described as sub-conchoidal, splintery (e.g. nephrite), hackly (e.g. copper), &c.

Hardness.—By the hardness of a mineral is meant its capability of scratching other substances. Some minerals are so soft that they can be scratched by the finger-nail, others can be scratched by a knife or file, and others again are still harder. For expressing degrees of hardness, mineralogists make use of the following ten minerals as a *scale of hardness*, ranging successively from talc, the softest, to diamond, the hardest.

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluor-spar.
5. Apatite.
6. Felspar.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

Nos. 1 and 2 on the scale can be scratched by the finger-nail; Nos. 1–6 by a knife, though No. 6 only with difficulty. No. 6 will scratch ordinary window-glass, but not so easily as will No. 7. Tests such as these will give a first rough idea of the hardness of an unknown mineral. To determine its hardness on the scale, we must find the scale-mineral that it can only just scratch, and the lowest one that it can be scratched by. Thus, if a mineral scratches calcite about as easily as it can itself be scratched by fluor-spar, its hardness may be expressed as 3½. In applying this test it is best to rub a sharp corner of the scratching mineral across a smooth surface of the mineral to be scratched; the powder produced should be wiped off, and the surface carefully examined with a lens, to make sure whether a scratch has really been produced or only powder rubbed off the corner of the scratching mineral. In selecting a smooth surface, such as a cleavage surface or a crystal face, care must be taken that the specimen is not damaged or a good crystal spoilt. Nothing looks worse in a collection of minerals than a scratched and damaged specimen. Earthy or loose aggregates of crystals do not, of course, show by scratching the true hardness of a mineral.

Magnetic and Electrical Properties.—Magnetite being the only strongly magnetic mineral, mention of this property may be deferred until we come to a description of the mineral itself. Most minerals, except metals and metallic ores (which are good conductors), acquire a charge of electricity when rubbed; sulphur and amber so acquire a negative charge, and most gem-stones a positive charge. Some few acquire an electrical charge when heated (see tourmaline).

Touch, Taste, and Smell.—Some minerals are greasy or soapy to the touch—for example, talc, which for this reason is sometimes called soap-stone; others have a rough, harsh feel. A few minerals which are soluble in water possess a characteristic taste—for example, salt and epsom-salts. A few others have a characteristic smell—for example, the bituminous odour of asphaltum. Clays when breathed upon have an earthy odour. Iron-pyrites and mispickel, when struck, emit, respectively, a sulphurous and a garlic-like odour.

CHAPTER IV.

The Chemical Composition and Classification of Minerals.

MINERALS being chemical elements and compounds, it is necessary in order to properly understand them to have some knowledge of chemistry. Of the eighty different kinds of elementary matter known to chemists, all are found in minerals; and for the majority of them, minerals are the only source. All the inorganic products prepared by the manufacturing chemist are derived directly from minerals. The more common chemical elements (forty-one in number) which are present as essential constituents of the minerals described in this book are given in the following table, together with their chemical symbols * and their atomic or combining weights. Several other rarer elements may also be present in these minerals; for example, pitchblende contains the elements radium, helium, and argon, and zinc-blende often contains the elements cadmium, gallium, and indium. It will be noticed that the abundant element nitrogen is not represented in the table; the explanation of this is that nitrates and ammonium salts, being all soluble in water, are of rare occurrence as minerals.

	Symbol.	Atomic weight.		Symbol.	Atomic weight.
Aluminium	Al	27	Carbon	C	12
Antimony (Stibium)	Sb	120	Chlorine	Cl	35·5
Arsenic	As	75	Chromium	Cr	52
Barium	Ba	137	Cobalt	Co	59
Beryllium	Be	9·1	Copper (Cuprum)	Cu	63·5
Bismuth	Bi	208	Fluorine	F	19
Boron	B	11	Gold (Aurum)	Au	197
Calcium	Ca	40	Hydrogen	H	1

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* When these are derived from the Latin name of the element this name is added in parentheses.

	Symbol.	Atomic weight.
Iron (Ferrum)	Fe	56
Lead (Plumbum)	Pb	207
Lithium	Li	7
Magnesium	Mg	24
Manganese	Mn	55
Mercury (Hydrargyrum)	Hg	200
Molybdenum	Mo	96
Niobium	Nb	93·5
Nickel	Ni	58·7
Oxygen	O	16
Phosphorus	P	31
Platinum	Pt	195
Potassium (Kalium)	K	39
Silicon	Si	28
Silver (Argentum)	Ag	108
Sodium (Natrium)	Na	23
Strontium	Sr	87·6
Sulphur	S	32
Tin (Stannum)	Sn	119
Titanium	Ti	48
Tungsten (Wolfram)	W	184
Uranium	U	238·5
Vanadium	V	51·2
Zinc	Zn	65·4
Zirconium	Zr	90·6

Of the elements enumerated above only four—namely, oxygen, hydrogen, fluorine, and chlorine—are gases when in their free state; only one is liquid—namely, mercury; and all the others are solid at the ordinary conditions of temperature and pressure. The gases, together with carbon, boron, silicon, sulphur, and phosphorus, are classed as non-metallic elements, all the others being metals.

The chemical compounds met with as minerals consist, in most instances,* of a combination of one or more metallic elements with one or more non-metallic elements. These are combined together in definite proportions. For example, iron-pyrites consists of a combination of one atom of iron with two atoms of sulphur—that is, 56 parts by weight of iron with $32 \times 2 = 64$ parts by weight of sulphur. The actual weights (grams or tons) is immaterial, since the atomic weights or combining weights as given in the above table are only ratios. The chemical symbol, or formula, for iron-pyrites is then FeS_2; this not only expresses that the compound is disulphide of iron, but it also enables us to calculate the percentage weight of each constituent—namely, 46·6 per cent. of iron and 53·4 per cent. of sulphur. Again, calcite is a combination of 40 parts by weight of calcium, with 12 parts of carbon, and $16 \times 3 = 48$ parts of oxygen, the formula being $CaCO_3$, which expressed in words is carbonate of calcium.

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* A notable exception is the common mineral quartz.

In order fully to determine the nature of a mineral, it is necessary to analyse it by the ordinary methods of chemical analysis; and even for purposes of identification it is often necessary to apply some simple chemical tests. Mineral carbonates, for example, can always be recognised by the fact that they effervesce in acids. Sulphur is readily tested for by heating the powdered mineral with sodium carbonate before the blowpipe on charcoal, and moistening the fused mass with water on a silver coin; if sulphur is present a characteristic black stain will be produced on the silver. At the same time, if a heavy metal is present in the mineral, a bead of the metal will be formed on the charcoal.

Two very important principles relating to the chemistry of minerals are those of polymorphism (including dimorphism) and isomorphism. Several cases are known in which totally distinct minerals are identical in chemical composition. For example, diamond and graphite both consist simply of the element carbon; but they consist of carbon crystallised in different forms, so that, although chemically alike, they are quite distinct, or *dimorphous*, substances. Again, calcium carbonate ($CaCO_3$) crystallises in nature either as calcite or as aragonite, which also are two quite distinct minerals. The most remarkable case, however, is that of the compound titanium dioxide, which is met with in nature as the three minerals rutile, anatase, and brookite; these, though chemically identical, are distinct in the form of their crystals and in all their physical characters. Another instance of trimorphism is given by the minerals kyanite, andalusite, and sillimanite (see Chapter XII.).

On the other hand, we may have minerals of different chemical composition appearing in crystals that are almost identical in form; such minerals are said to be *isomorphous*. Of this there are numerous examples amongst minerals, one of the best being that given by the group of rhombohedral carbonates. The carbonates of the chemically related elements calcium, magnesium, iron, zinc, and manganese all crystallise in rhombohedra with very nearly the same angles between their faces. But not only this, they are capable of so intimately growing together that they may all help to build up one and the same crystal. The tiny crystalline bricks of these different substances are so nearly alike in their shape that they will all fit into the same structure. We then have what is called a mixed crystal, consisting of two or more of these carbonates mixed together in variable proportions. In such cases the chemical composition of the crystal cannot be fully expressed by a simple chemical formula.

The *classification* adopted in the descriptive portion of this book is a strictly chemical classification, on the same lines as in the modern treatises on scientific mineralogy. In the first group are placed the chemical elements; in the next three the sulphides, haloids, and oxides, respectively; and in succeeding groups the large number of oxygen-salts, these being subdivided according to the acid which enters into combination with a metal to form the various salts, such as carbonates, sulphates, phosphates, silicates, &c.* Within each of these groups, minerals which are isomorphous with one another are placed together. In an appendix a few organic substances, which, strictly speaking, are not definite mineral species, are brought together.

Other systems of classification are of course possible. For example, in the eighteenth century, before the development of modern chemistry, natural history systems of classification were in vogue. These took account only of the external characters of minerals, and naturally lead to very deceptive results; since totally distinct minerals may often closely resemble one another in their general appearance and colour. Another method of classification, and one which is often used at the present day, is to group minerals according to the metals they contain. But this system, though of convenience to the practical miner, is not altogether satisfactory, since, unless duplication is to occur, certain minerals must be arbitrarily allocated to one group or another.

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* An enumeration of the minerals placed under each of these headings will be found in the List of Plates, p. vi.

As an example of such a classification, based on economic lines, the following may be given. This will, at the same time, give some idea of the practical uses of the minerals described in the present volume. A certain amount of duplication is here unavoidable; for example, mispickel appears with the ores of iron, but being of more importance as an ore of arsenic, it also finds a place under this metal. Linarite comes under both copper and lead. Again, quartz appears amongst the precious stones, the rock-forming minerals, and the abrasives. On the other hand, several interesting, though commercially valueless, minerals, which will be described farther on, do not fall into this classification.

METALLIC ORES.

Gold: Native gold.
Silver: Native silver, Pyrargyrite, Proustite, Tetrahedrite.
Copper: Native copper, Copper-pyrites, Tetrahedrite, Atacamite, Chessylite, Malachite, Linarite, Cuprouranite.
Platinum: Native platinum.
Lead: Galena, Cerussite, Anglesite, Linarite, Crocoite, Wulfenite, Pyromorphite, Vanadinite.
Zinc: Zinc-blende, Calamine.
Iron: Iron-pyrites, Marcasite, Pyrrhotite, Mispickel, Hæmatite, Magnetite, Limonite, Chalybite, Vivianite.
Manganese: Manganite, Pyrolusite, Psilomelane, Rhodochrosite.
Nickel: Niccolite.

Cobalt: Smaltite, Erythrite.
Mercury: Cinnabar.
Tin: Cassiterite.
Tungsten: Wolframite, Scheelite.
Uranium: Pitchblende, Cuprouranite.
Vanadium: Vanadinite.
Chromium: Crocoite.
Molybdenum: Molybdenite, Wulfenite.
Arsenic: Native arsenic, Realgar, Orpiment, Mispickel.
Antimony: Native antimony, Stibnite.
Bismuth: Native bismuth.

PRECIOUS STONES (GEM-MINERALS).

Diamond, Corundum, Opal, Quartz (Amethyst, Smoky-quartz, Rock-crystal, Cat's-eye, Rose-quartz, Agate, Jasper), Zircon, Turquoise, Beryl, Garnet, Olivine, Idocrase, Topaz, Epidote, Tourmaline, Amber.

ROCK-FORMING MINERALS.

Quartz group, Felspar group, Amphibole group, Pyroxene group, Sodalite, Leucite, Olivine, Idocrase, Mica and Chlorite groups, Serpentine, Talc.

SPARRY MINERALS (SPARS).

Fluor-spar, Calcite (calc-spar), Aragonite, Barytes (heavy-spar), Celestite, Gypsum.

ABRASIVES.

Diamond, Corundum (emery), Quartz, Garnet.

SALTS (SOLUBLE IN WATER).

Rock-salt.

INFLAMMABLES.

Organic substances (Amber, Asphaltum, Coal, &c.), Graphite, Diamond, Sulphur.

CHAPTER V.

The Native Elements.

Although some eighty different kinds of elementary matter have been identified by chemists in the materials of the earth's crust, yet only few of these are found in a free state in nature. The gaseous elements, oxygen and nitrogen, which form the bulk of our atmosphere, can scarcely be regarded as minerals; though the former, when in chemical combination, is present in a large number of minerals. The chemical elements may be roughly divided into two great groups—the non-metallic and the metallic elements. Belonging to the former group we find as minerals the elements carbon and sulphur; and in the latter group we have the native metals copper, silver, gold, and platinum, and the so-called semi-metals arsenic, antimony, and bismuth.

Carbon, though abundant in the organic world, and present also in chemical combination in limestone rocks and the mineral carbonates, is of rare occurrence as a native mineral. It is found crystallised in two quite distinct forms, which as minerals are known as diamond and graphite. The other chemical elements met with as minerals are known by their ordinary or chemical names, sometimes preceded by the word 'native': thus, we may speak of sulphur or native sulphur, gold or native gold, &c.

Non-metallic Elements.

Diamond (Plate 1, Fig. 1).—Diamond is perhaps the most remarkable and interesting of all minerals, and for this reason it will be treated in rather more detail than the other species. One would little imagine that such a brilliant, transparent, colourless, and at the same time intensely hard gem is composed merely of carbon, our usual idea of which is a black, opaque substance, so soft that it soils the fingers.

When heated in air, or better still in oxygen, a diamond burns with a small bluish flame, and gradually disappears. The product of combustion is the gas carbon dioxide, identical with that produced when any other form of carbon burns in the air. Diamond is, in fact, pure carbon; but, conversely, pure carbon is not necessarily diamond. We must have the carbon crystallised, and, moreover, the crystals must be of a particular form, for, as already mentioned, graphite is also a crystallised form of carbon.

Crystals of diamond belong to the cubic system. They most commonly present the form of the regular octahedron —that is, a solid bounded by eight equilateral triangles (Text-Fig. 1, p. 8). The crystal seen partly embedded in the matrix in Plate 1 is of this form. Less frequently the crystals have the form of the cube (Text-Fig. 2) or the rhombic-dodecahedron (Text-Fig. 5). A peculiarity presented by crystals of diamond is that their faces are usually curved and their edges rounded, and sometimes this rounding is so pronounced that the crystals are almost spherical in form. Again, the faces are frequently beautifully marked with tiny triangular pits or depressions.

The great hardness of diamond is one of its most remarkable features. It is by far the hardest of all known substances, whether natural or artificial. There is nothing that it will not scratch with ease. This was well known to the ancients, who called the stone *adamas*, on account of its adamantine or unconquerable nature; and it is from this word that our name diamond is derived. The ancients believed that a diamond could not be broken, but would rather shatter the hammer and anvil. There is, however, an important difference between hardness and frangibility, and, as a matter of fact, diamond is quite brittle.

Further, diamond has the peculiar property of splitting with ease along certain directions in the crystal. There are four such directions of easy splitting, or cleavage, which are parallel to the four pairs of parallel faces of the octahedron. In these directions the fractured surfaces are perfectly plane and smooth.

The specific gravity of diamond is 3·52 (that is, a diamond is three and a half times heavier than an equal volume of water), being considerably higher than that of other forms of carbon; the specific gravity of graphite, for example, is only 2·2. We thus see that in diamond the ultimate particles of carbon must be very closely packed together; and it is this close packing, according to a regular and symmetrical plan, that gives to diamond its particular crystalline form and its unique physical properties.

Of other physical characters of the diamond, some mention must be made of its optical properties, or its behaviour with respect to light, since on these largely depends its use as a gem. The index of refraction is very high, and consequently a ray of light travelling from air into diamond will be more strongly bent, or refracted, than a ray passing from air into water or ordinary glass. Further, the exact value of the index of refraction depends on the colour of the light, being 2·407 for red light, and 2·465 for violet light. A prism of diamond, therefore, gives a much longer coloured spectrum than many other transparent substances; in other words, the dispersion, or dispersive power, is high. It is owing to this high dispersive power that a faceted diamond displays its brilliant flashes of rainbow colours. The high refractive index is the cause of the marked brilliancy, or fire, shown by a faceted diamond. Connected also with the high refractive index we have the characteristic adamantine lustre, which enables a diamond to be recognised at sight by the experienced eye. On the rough surfaces of the less clear stones this lustre is almost metallic in character, and, indeed, some crystals have almost the appearance of metallic lead.

In the colour of diamond there is a considerable range. Perfectly pure crystals are colourless and transparent, or water-clear, and are described in the trade as stones of the 'first water.' Other crystals range from pale yellow to dark brown or even black, whilst, less frequently, the colour may be pronounced shades of blue, green, or red. These colours are due to the presence of mere traces of colouring matter in the material of the diamond itself.

Diamonds are of quite local distribution, and in Europe the only recorded occurrence is in the Ural Mountains. The principal diamond-producing countries are South Africa, India, and Brazil; other occurrences of less importance are those of Borneo, New South Wales, British Guiana, and the United States of North America. Although the gem has been obtained from India ever since the time of the Romans, it was not discovered in Brazil until the year 1725, and in South Africa not until 1867. At the present time the diamond-mining industry of South Africa is in a very flourishing condition, and far more diamonds have been found there than in India and Brazil together for centuries.

The usual mode of occurrence is in the sands and gravels of river-beds. By a simple process of washing in a shallow dish, called in Brazil a 'batea,' the lighter materials are carried away in a stream of water, leaving behind the diamond with the other denser stones. In India and Brazil some of these diamantiferous deposits are of great antiquity, and the sand and pebbles are cemented together to form a solid rock known as conglomerate. The materials of these secondary deposits must clearly have been derived by the weathering and breaking down of pre-existing rocks; but in India and Brazil the original rock which supplied the diamond has never yet been discovered.

In South Africa, on the other hand, the diamonds, which were at first found amongst the gravels of the Vaal River, were very soon traced to volcanic pipes in the neighbourhood; and when this discovery was made the town of Kimberley very quickly sprang up on the spot.

These volcanic pipes are of a rather special kind. At the surface they have a more or less circular or oval outline, with a diameter of 200 to 300 yards, and they project only slightly above the general level of the ground. Downwards they extend to unknown depths, passing through horizontal strata of shale, diabase, and quartzite. The material filling the pipes is known locally as 'blue ground,' though usually it is more of a dark greenish shade, as represented in Plate 1. It is really a mixture of materials, and consists largely of the alteration products of rocks rich in the mineral olivine. Chemically, the 'blue ground' is essentially a hydrated silicate of magnesium. In structure the material is broken and fragmentary, and it has no doubt been brought up into the pipes from an underground reservoir of molten rock by a series of steam explosions under high pressure. There does not appear to have been any active volcano discharging material at the earth's surface. The diamonds are found embedded in this material; that they also were brought up into the pipes by the same series of explosions is abundantly proved by the fact that the crystals are often broken and fragmentary. The 'blue ground' is thus not the original mother-rock of the diamond, and the exact nature of this still remains unknown, though probably it was an olivine-rock.

The actual amount of diamond present in the 'blue ground' is relatively very small, only 2 to 5 millionths per cent., and a specimen showing a crystal actually embedded in the matrix (as in Plate 1, representing a specimen from Kimberley) is a rarity. Large quantities of the rock have therefore to be extracted by mining operations—from the upper portions of pipes by open workings, and at greater depths by a regular system of underground mining. The excavated rock is spread out on extensive and specially guarded 'floors,' where it is watered, harrowed, and exposed to the weather for about a year. After this treatment it is soft enough for crushing, and the heavy minerals (diamond, garnet, ilmenite, &c.) are separated by specially constructed washing machinery. From this heavy residue the diamonds were formerly picked out by hand, but now it is passed over a vibrating table with a greased surface; the diamonds have the curious property of adhering to the grease, whilst the other minerals slide off.

In the neighbourhood of Kimberley, in Cape Colony, there are several of these diamond-bearing pipes, and there are others in Orange River Colony and in the Transvaal. By far the largest pipe is one situated about twenty miles W.N.W. of Pretoria, which was discovered in 1902, and is worked as the Premier mine. This pipe measures half a mile across, and it is further remarkable in having produced the largest known diamond, namely, the 'Cullinan.'

Another mode of occurrence of diamond remains to be mentioned—one which, though of no practical importance, is of considerable scientific interest. Microscopic diamonds have been detected in a few of the meteoric stones and irons which as shooting stars have fallen to our earth from surrounding space.

This mode of occurrence has a bearing on the artificial production of diamond. By dissolving carbon in molten iron and by cooling the mass rapidly under an enormous pressure, microscopic diamonds have resulted; and similar results have been obtained by dissolving carbon in molten olivine.

As to the practical applications of diamond, its use in jewellery is too well known to need more than a passing mention. In the operation of fashioning a faceted gem, the rough stone is first reduced to a suitable size and shape by taking advantage of the property of cleavage. The general form is then produced by rubbing two diamonds together—a process known as 'bruting'; and the facets are finished by grinding on a rapidly revolving disc or lap of iron, the grinding material being diamond powder itself. The form of cutting most usually adopted is the brilliant, and cut diamonds are consequently often known in the trade simply as brilliants. For small, flat stones the less effective rose-cut is the form sometimes employed.

Certain important technical applications of the diamond depend on the great hardness of the material, which, as already mentioned, far exceeds that of all other substances. The glazier's diamond consists of a crystal with a naturally rounded edge; sharp cleavage splinters of diamond are used for writing on glass. Diamond powder is much used by lapidaries and gem-cutters, it being, in fact, the only material with which diamond can be ground and polished. Extensive use is made of diamond for rock-drills; the cloudy, rounded crystals known as *bort*, and the black, granular variety called *carbonado*, being used for this purpose. The stones are embedded by pressure in the steel crown of the drill.

We cannot conclude this account of the mineral diamond without reference to some of the more noteworthy of the large and famous cut gems, about which, indeed, it would be possible to write a whole volume of romance.

Several large gems were seen in India by the French traveller Tavernier about the middle of the seventeenth century. Large Indian diamonds were, however, known in Europe long before that time, for Charles the Bold, Duke of Burgundy (1433–77), was the possessor of the 'Florentine' and the 'Sancy' diamonds. After many vicissitudes of fortune these gems are now, one with the Austrian crown jewels, and the other in the possession of an Indian prince; they weigh 133¼ and 53¾ carats,* respectively.

The 'Koh-i-noor' (a name meaning 'Mountain of Light') was taken in 1739 by Nadir Shah, the Persian conqueror of the Mogul Empire, and in 1850 it was presented by the East India Company to Queen Victoria. In its Indian form of cutting it weighed $186\frac{1}{16}$ carats, but this was reduced by re-cutting in England to $106\frac{1}{16}$ carats.

Most of the historic diamonds are of Indian origin, only one or two coming from Brazil. But during recent years much larger stones have been found in comparatively large numbers in the South African diamond-mines. These are, indeed, sometimes too large for cutting into a single gem, and they have to be divided by cleavage. This was the case with the 'Excelsior,' a stone of 969½ carats, found in 1893 in the Jagersfontein mine, Orange River Colony; and also the 'Cullinan,' which was found in 1905 in the Premier mine near Pretoria, Transvaal. The 'Cullinan' is by far the largest diamond yet discovered, weighing in the rough no less than 3025¾ English carats (=621·2 grams), or nearly 22 oz. avoirdupois. It was presented by the Transvaal government to King Edward VII. in 1907, and has since been cut into nine large brilliants and ninety-six small brilliants. The two largest brilliants, weighing 516½ and $309\frac{3}{16}$ carats, are each far larger than any other cut diamond.

Graphite (Plate 1, Fig. 2).—Like diamond, this consists simply of the chemical element carbon; but although these two minerals are identical in chemical composition, they exhibit the most marked differences in their physical characters. Diamond is the hardest, whilst graphite is the softest of minerals. Diamond is colourless and perfectly transparent, whilst graphite is black and opaque; diamond is a non-conductor of electricity, and graphite is a good conductor. There

* 151½ English carats equals 1 oz. troy.

is also a very marked difference in the specific gravity, that of diamond being 3·52, whilst that of graphite is only 2·2. Again, whilst diamond is nearly always found as well-developed octahedral crystals, graphite is only rarely found as small and indistinct, six-sided scales. More usually the material is very imperfectly crystallised, taking the form of scaly, lamellar, or fibrous masses. These striking differences between diamond and graphite are to be attributed to the different, but in each case orderly, grouping of the ultimate particles of carbon—that is, to a difference in the crystalline structure of the material.

Scales of graphite may be readily divided into still thinner leaves; in other words, they possess a perfect cleavage parallel to their large surface. The material is iron-black in colour, with a metallic lustre. It is greasy to the touch, and soils everything it comes in contact with. On this depends, of course, its well-known use for making pencils (the so-called 'lead pencils,' which contain no lead!); and, indeed, the name graphite is derived from the Greek word meaning 'to write.' Plumbago is another name for this mineral.

The better qualities of material, such as are used for making pencils, contain a certain amount of impurity, which remains behind as ash when the graphite is burnt. Inferior qualities, containing still more impurity, are used for making stove-polish, foundry facings, crucibles, &c. The purified material, consisting of fine scales floated off in water, is employed as a dry lubricant.

Graphite occurs mainly in the older crystalline rocks, in which it forms veins or irregular masses; and it is mined principally in Ceylon, Siberia, the State of New York, and Canada. The famous Borrowdale mine, near Keswick, in Cumberland, was worked since the beginning of the seventeenth century, and possibly earlier; but this mine is now exhausted. At the present time a certain amount of commercial graphite is prepared artificially in the electric furnace.

Sulphur (Plate 1, Fig. 3).—This mineral frequently occurs beautifully crystallised, and the crystals are transparent and of a bright primrose-yellow colour. Pretty specimens like that represented in Plate 1 are not at all uncommon, and with their bright and attractive colour they form conspicuous objects in any collection of minerals. In this picture we see several crystals with sharply defined planes and edges scattered over the surface of a matrix consisting of minutely crystallised calcite. The characteristic form of the crystals is clearly shown; they are rhombic (four-faced) pyramids, truncated by a rhomb-shaped face at their summits. The system of crystallisation is orthorhombic, and the crystals have three planes of symmetry.

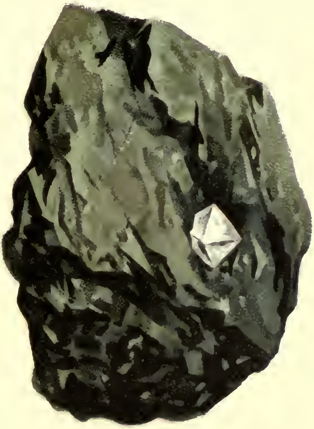
The crystal faces are always very bright and smooth, with a lustre like that of resin. There is no cleavage, and the fractured surfaces are typically conchoidal. The material is quite soft (H. = 2), though very brittle; and it is not at all heavy (sp. gr. = 2·07). It is a bad conductor of heat; and for this reason a crystal of sulphur when held in the warm hand emits a crackling noise and becomes fissured. Good specimens must, therefore, be handled with care.

The chemical properties of sulphur are well known to students of chemistry. When heated, the material readily melts to a dark-brown, viscous liquid, and in the air it burns with a small blue flame, producing a most penetrating and suffocating odour. The product of combustion is the gas sulphur dioxide (SO_2), the sulphur having entered into chemical combination with the oxygen of the air. Sulphur is dissolved by the liquid carbon disulphide, and as the solution slowly evaporates it deposits brilliant rhombic pyramids of the same form as the natural crystals.

Like the element carbon, sulphur also exists in more than one crystalline modification. When molten sulphur solidifies, it takes the form of long, spear-shaped crystals, which belong to the monoclinic system, and have the lower specific gravity of 1·86. These crystals are, however, not stable at the ordinary temperature. After a short time cloudy patches of a pale yellow colour make their appearance in the amber-yellow crystals; these gradually spread, and finally the crystals fall to powder. Under the microscope this powder is seen to consist of minute orthorhombic crystals. There has thus been a spontaneous conversion of the unstable monoclinic sulphur to the more stable orthorhombic sulphur; and for this reason the monoclinic modification of sulphur is unknown as a natural mineral. On the other hand, the two crystalline modifications of carbon are both stable at the ordinary temperature, and they are consequently both found in nature as minerals.

Sulphur is found in all volcanic districts, it being a common product of sublimation from the sulphurous gases of volcanoes. This sublimed sulphur is, however, never distinctly crystallised; it forms powdery and earthy, or sometimes more compact and stalactitic masses. The beautifully crystallised specimens of sulphur are found in crevices in beds of clay and marl, together with crystals of gypsum, calcite, aragonite, and celestite.

The best-known locality for such crystals is in the neighbourhood of Girgenti, in Sicily—a district far removed from Mount Etna—and the materials here are not of volcanic origin. The specimen represented in Plate 1 is from this locality. In this district there are numerous sulphur-mines. The native sulphur is separated from its matrix by fusion, and the crude sulphur so obtained is further purified by sublimation, giving 'flowers of sulphur.' This is then fused and cast into sticks to give the roll-sulphur of commerce.



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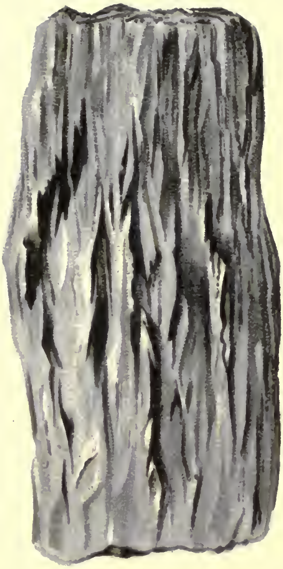

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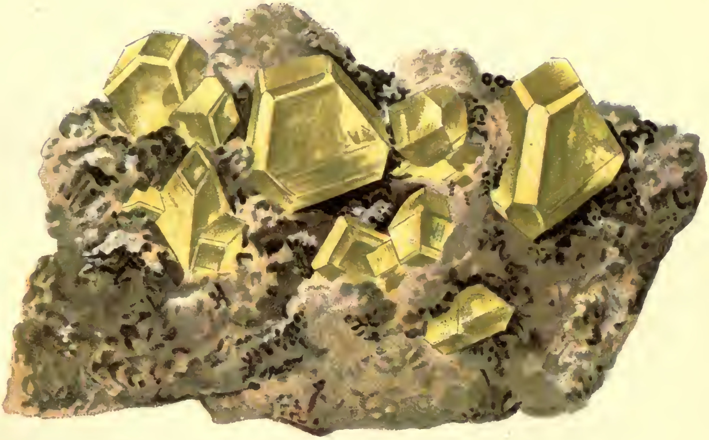


3

1, Diamond. 2, Graphite. 3, Sulphur.

Sulphur has many important technical applications. It is used in medicine; in the manufacture of matches, gunpowder, and fireworks; for vulcanising india-rubber; in the preparation of sulphuric acid (oil of vitriol), ultramarine, and many other sulphur compounds. Much of the oil of vitriol of commerce is now prepared from iron-pyrites, but this is not so pure as that obtained from sulphur. The sulphur dioxide produced by burning sulphur in the air is extensively used for disinfecting and bleaching purposes, and in the boiling of wood-pulp employed in the manufacture of paper.

In chemical combination sulphur is present in several kinds of minerals. The sulphides are compounds of sulphur with a metal, and the sulphates contain oxygen in addition to sulphur and a metal.

SEMI-METALLIC ELEMENTS.

In this class we have the native elements arsenic, antimony, and bismuth, which, though possessed of a metallic lustre and high specific gravity, approach the non-metals in some of their chemical properties. They are closely related to each other chemically, being isomorphous, and form a progressive series with arsenic at the non-metallic and bismuth at the metallic end of the series. The progressive nature of this series is well shown by the specific gravities, which are 5·7, 6·7, and 9·8, respectively, in arsenic, antimony, and bismuth. As minerals they are of comparatively rare occurrence, and for commercial purposes these elements are more often extracted from their compounds, which occur in nature mostly as sulphides.

Arsenic (Plate 2, Fig. 1).—Native arsenic is usually found as masses with a rounded (mamillated) surface and an internal shelly structure. The characteristic form of surface is represented in the picture. Freshly fractured surfaces are tin-white, with a metallic lustre; but on exposure to the air these very soon tarnish, and become dull and dark grey.

This mineral occurs in metalliferous veins, together with ores of silver and cobalt. It is found in the Harz Mountains and in Saxony. Globular masses of radiating crystals are found embedded in clay at Akatani, in Japan.

Antimony (Plate 2, Fig. 2).—Native antimony is found as granular or lamellar masses, which have a tin-white colour and metallic lustre. There is a perfect cleavage in one direction. It occurs in metalliferous veins, usually with ores of silver, at but few localities—for example, in Sweden and Borneo.

Bismuth (Plate 2, Fig. 3).—Native bismuth is met with as reticulated or feathery forms, and also as granular masses. It usually shows a yellowish tarnish, but a freshly fractured surface is silver-white, with a characteristic tinge of red. It is found in metalliferous veins in Cornwall, Saxony, Bolivia, and Queensland.

Distinctly developed crystals of bismuth, though rare in nature, are readily prepared artificially by fusion. The metal is melted in a crucible, and after it has cooled for a little while the crust is broken and the still molten portion poured out. The interior of the crucible is then seen to be completely lined with sharply formed crystals, which have sunken faces and a brilliantly coloured iridescent tarnish on their surface. Very pretty groups of crystals are obtained in this way. These crystals have the appearance of cubes, but in reality are rhombohedra, the faces being not quite at right angles to one another. Further, there being only one direction of cleavage (perpendicular to the principal axis), only two of the opposite corners of the apparent cubes can be truncated by cleavage.

A certain quantity of commercial bismuth is obtained from native bismuth, especially in Bolivia, and the remainder is extracted from the sulphide (bismuthinite, Bi_2S_3). It is largely used for making readily fusible alloys, which find an application in the safety-plugs of boilers and fire-extinguishers. Salts of bismuth are extensively used in medicine for relieving indigestion.

METALLIC ELEMENTS.

Silver (Plate 2, Figs. 4 and 5).—The useful metal silver occurs native as a mineral, but as a source of the metal the various ores of silver are of much greater importance, whilst a considerable amount is extracted from ores of lead, which always contain a small proportion of silver.

Native silver is found principally in the upper levels of silver-mines, it having resulted by the secondary alteration, or weathering, of various silver-bearing minerals. It is met with in cavities in the ore as fine, twisted, wire-like forms. This form is extremely characteristic of native silver; the wires are usually finer than represented in the picture (Fig. 5). Under these conditions it is found in Cornwall and Saxony, and more abundantly in the silver-mines of Mexico and Chile.

Crystals of native silver are quite rare. They belong to the cubic system, and usually have the form of distorted cubes (Fig. 4). Most of the crystallised specimens to be seen in mineral collections have come from the silver-mines at Kongsberg, in Norway, this being the locality of the specimen represented in Fig. 4. Masses of native silver weighing as much as 5 cwt. have been found in these mines.

The specific gravity of native silver ranges from 10 to 11, this variation being due to the presence of small amounts of gold or copper alloyed with the silver.

Platinum (Plate 3, Fig. 1).—This metal was first brought to Europe in the year 1735 from Colombia, South America. Being a white metal, resembling silver in appearance, it was called platina in Spanish, *plata* being the Spanish name for silver. It differs from silver, however, in its very high specific gravity, which ranges from 14 to 19 in the native metal (this variation being due to the presence of impurities, principally iron), and is as high as 21·5 in the chemically pure metal. With the exception of iridium and osmium, it is the heaviest of metals, and, indeed, of all kinds of matter. It also differs from silver in being fusible only with great difficulty, and in being very resistant to acids.

These latter properties make the metal invaluable for the construction of certain kinds of chemical apparatus, such as crucibles, basins, wire, and foil. The metal is of rare occurrence, and owing to the limited supply the price is constantly rising. Formerly the metal was coined in Russia, but now its value is greater than that of gold.

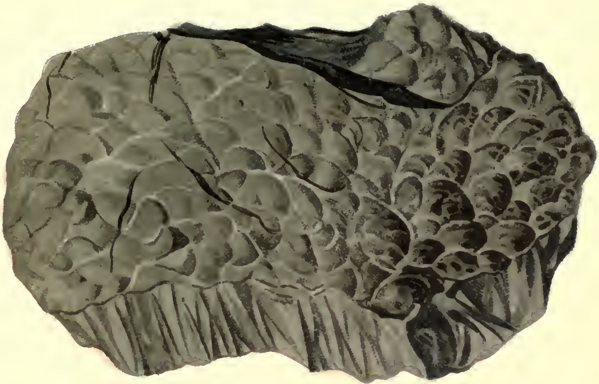
Native platinum is found as grains and small nuggets (Plate 3, Fig. 1) in the beds of streams. Particles of chromite (chrome iron-ore) are sometimes seen attached to the nuggets, proving that the material has been derived from the olivine-rocks which outcrop in the neighbourhood. Practically the whole of the platinum used commercially comes from the Ural Mountains.

The only source of platinum is the native metal, but the element is also known to occur in the tiny crystals of the rare mineral sperrylite, an arsenide of platinum, found in Canada.

Gold (Plate 3, Figs. 2–4).—Though of sparing occurrence, gold is a very widely distributed mineral, and it is found in the native state in almost every country of the world. Being found as grains and nuggets in the beds of streams and rivers, it must have attracted the attention of man at a very early period, and gold ornaments have been unearthed from the burial-places of prehistoric man.

Well-shaped crystals of gold are small and very rare; they

METALLIC ELEMENTS.



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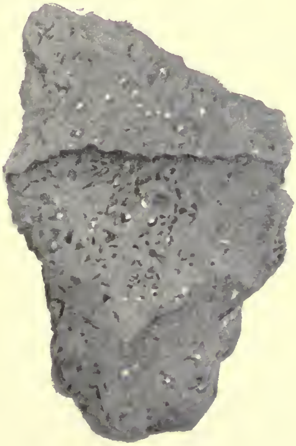

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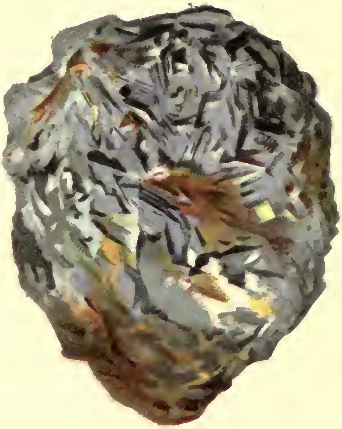

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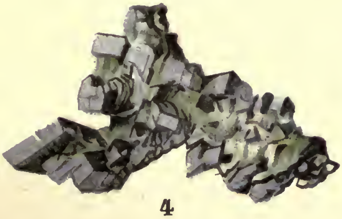

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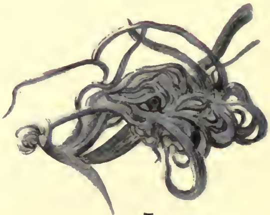

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1, Arsenic. 2, Antimony. 3, Bismuth. 4, 5, Silver.

have the form of the regular octahedron or cube, usually with rounded edges. A small group of gold crystals is represented in Plate 3, Fig. 2. Thin plates of gold (so-called leaf-gold), bearing delicate crystalline markings on their surfaces, are rather more frequent, and examples from Transylvania in Hungary, and Colombia in South America, are well known. Alluvial gold, as found in the beds of streams and rivers, has the form of scales, grains, and rounded nuggets; while in gold-quartz, the precious metal takes the form of veins and irregular patches (Figs. 3 and 4). The largest mass of native gold on record was a nugget called the 'Welcome Stranger,' found in Victoria, Australia, in the year 1869; it weighed 156 lb. avoirdupois, and was valued at £9534.

Native gold is never quite pure, but is always alloyed with from 1 to 38 per cent. of silver. The greater the amount of silver present, the lower is the specific gravity (which ranges from 15 to 19), the paler the yellow colour, and the greater the hardness.

Pure gold is as soft as lead—too soft, indeed, for use in coinage and jewellery. Its hardness and durability are increased by alloying it with copper, or sometimes with silver. The amount of gold actually present in such an alloy is expressed as so many carats—that is, as so many parts in 24. Thus, 22-carat gold (as in the English gold coinage) means that in each 24 parts of metal 22 parts are of gold and 2 of base metal; and in 12-carat gold only half is pure gold.

Gold is separated from the sand and gravel of alluvial deposits by a simple process of washing, whereby the lighter materials are carried away in a stream of water, leaving the heavier gold behind. The finer particles are collected from this heavy residue by the addition of mercury, with which gold readily forms an amalgam. On being heated the amalgam the mercury is volatilised, leaving the gold. Being easily worked, such incoherent deposits are always the first to be attacked, and in many countries they are now exhausted. Recourse must then be had to the solid rocks, the working of which is a far more laborious operation. The gold-bearing rock taken from the mine is crushed to powder under heavy stamps, and the gold is dissolved by a dilute solution of potassium cyanide—a process known as the cyanide process. The gold is deposited from this solution by means of an electric current.

The mother-rock, or matrix, of gold is very often a white quartz (Plate 3, Figs. 3 and 4), which occurs as veins, traversing the older crystalline rocks. In the rich gold-fields of the Witwatersrand, or the 'Rand,' in the Transvaal, the matrix is, however, a hard, compact conglomerate, known locally as 'banket,' consisting of pebbles of quartz cemented together by a siliceous material. In this rock the gold is so finely divided that only rarely is it visible to the unaided eye. Gold is also found in metalliferous veins, together with iron-pyrites, ores of silver, &c. In some of these veins the gold exists not only in the native state, but also in chemical combination with tellurium. These tellurides of gold are of considerable importance as a source of gold at Kalgoorlie, in Western Australia, and at Cripple Creek, in Colorado.

When these solid gold-bearing rocks are broken down by the slow action of weathering agencies and their materials transported by running water, many of the accompanying minerals are destroyed; but the quartz and the gold, being indestructible, accumulate in the beds of streams and rivers, forming the alluvial deposits already mentioned. In this way the work of extracting gold from the solid rock is performed by nature herself.

In the British Isles, small nuggets, the largest weighing 27 oz., have been found in Cornwall, Scotland, and County

Wicklow. During the sixteenth century there were quite extensive gold-washings in the Leadhills district in Lanarkshire; while at the present day a thousand or more ounces of gold are annually extracted from the quartz-veins in the neighbourhood of Dolgelly, in Merionethshire.

The principal gold-producing countries are the Transvaal, Australia, and California. In the year 1907 the production for the whole world amounted to 604 tons of fine gold, and of this amount 365 tons was produced in the British Empire.

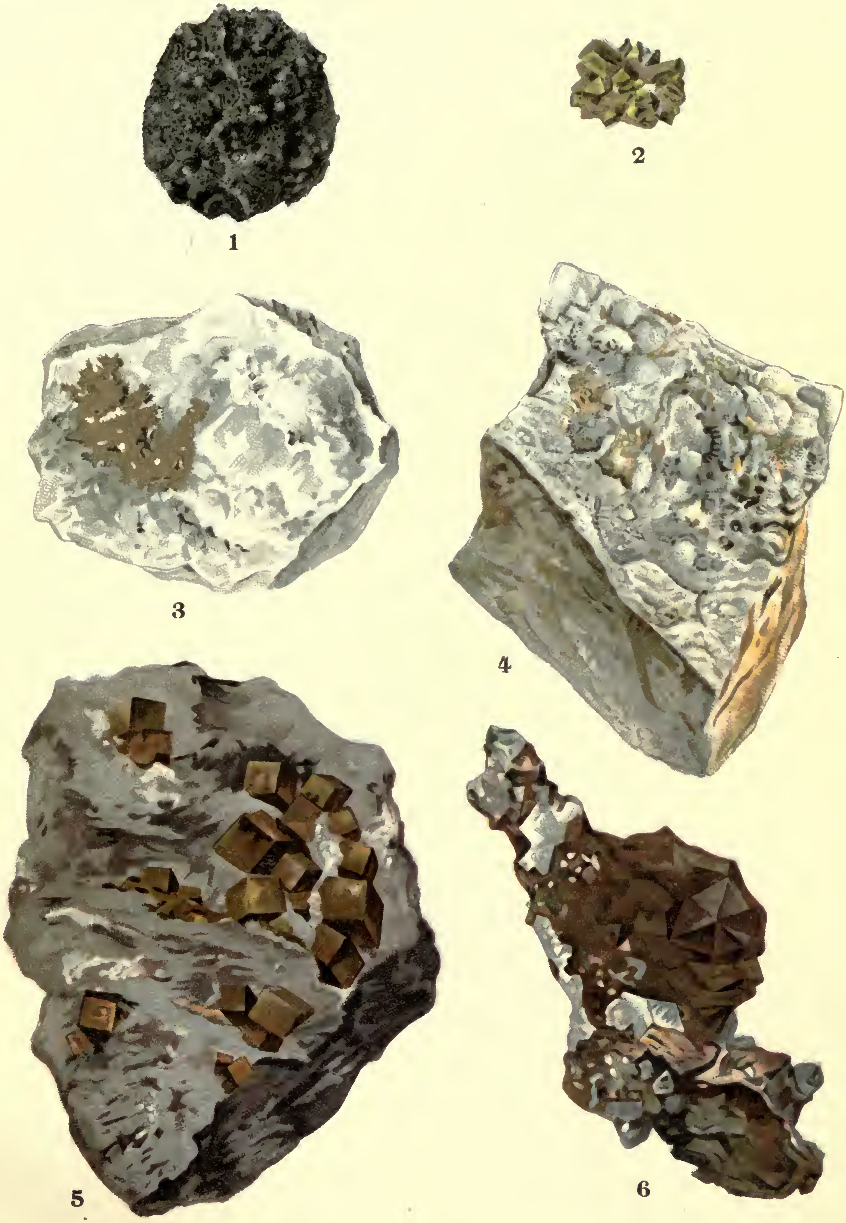
Copper (Plate 3, Figs. 5 and 6).—Like gold and silver, native copper crystallises in the cubic system, but distinctly formed crystals are here also of rare occurrence. Well-shaped cubes, such as represented in Fig. 5, are quite exceptional, and even the complex twinned crystals shown in Fig. 6 are but rarely met with. Usually the metal has the form of thin plates, filling narrow crevices in rocks of various kinds, such as sandstone, slate, or igneous rocks; and these plates frequently have a delicate frond-like or dendritic structure. Mossy aggregates are also common, particularly in the upper portions of veins of copper-ore, where the material has resulted by the decomposition of various copper-bearing minerals.

On its surface, native copper is usually dull and tarnished, with a dark chocolate-brown colour, or sometimes green (owing to the surface alteration of the material to green carbonate of copper); and only on a fresh fracture is the characteristic copper-red colour, with bright metallic lustre, to be seen. The native metal is usually almost chemically pure copper, and its specific gravity does not vary much from 8·9.

Small specimens of native copper are found in most copper-mines; but as a source of metal this mineral is of far less importance than copper-pyrites and other compounds of copper. In the State of Michigan, on the south shore of

Lake Superior, it exists in large quantities and is extensively mined; but owing to the toughness of the metal, the mining operations are attended with some difficulty. One mass of pure copper found at this locality was estimated to weigh as much as 420 tons. In the old copper-mines in the Lizard district of Cornwall, masses of copper up to 3 tons in weight were found embedded in the serpentine rock.

Iron.—We cannot conclude our description of the native elements without adding a brief mention of native iron. Although iron, in the form of its various chemical compounds, is of such abundance amongst the materials of the earth's crust, yet native iron is of the greatest rarity. This is readily explained by the fact that metallic iron is readily altered by oxidation when exposed to the weather. Small grains of metallic iron have been observed embedded in basaltic rocks at a few places, and in Greenland large masses have been found in basalt. But of special interest are the masses of metallic iron (invariably, however, alloyed with about 9 per cent. of nickel) which occasionally fall to our earth from outside space. Such a mass of meteoric iron, weighing 7¾ lb., fell at Rowton, in Shropshire, on April 20, 1876; and a mass weighing as much as 50 tons has been found in Mexico.



1, Platinum. 2—4, Gold. 5, 6, Copper.

CHAPTER VI.

The Sulphides, Arsenides, and Sulphur-salts.

In this class we have the sulphides and arsenides of the heavy metals, and also a few rarer minerals, in which both sulphur and arsenic (or antimony) enter into chemical combination with a heavy metal. Most of the minerals to be here described are of importance to the miner as ores. They are usually heavy and opaque, with a metallic lustre, thus somewhat resembling metals in their appearance; but some are quite transparent and brightly coloured. They occur, for the most part, in mineral-veins, or lodes, which intersect the older rocks of the earth's crust. The different kinds are frequently found together in the same vein, and they are also much intermixed with various sparry minerals. It is, therefore, part of the work of the miner, after he has raised the ore to the surface, to separate the different kinds of minerals, in order to prepare a product, or products, which can be dealt with by the smelter for the extraction of valuable metal.

Stibnite (Plate 4, Figs. 1 and 2).—This is a sulphide of antimony, with the chemical formula Sb_2S_3. It is also often known by the name antimonite, or antimony-glance, and it is the most important of the ores of antimony.

It is usually found as fibrous or lamellar masses, which break with shining flat surfaces, owing to the existence of a perfect cleavage in one direction in the crystals. A very characteristic feature of stibnite is that these bright cleavage surfaces are marked by fine striations in a direction at right angles to their length. Sometimes the fibrous or acicular crystals, which build up the massive material, have a radial or stellate arrangement, as represented in Fig. 1.

Crystals of stibnite belong to the orthorhombic system, and have the form of long prisms, varying from the thickness of a needle to an inch or more across. They are usually much grooved and furrowed in the direction of their length (Fig. 2); and the perfect cleavage is also parallel to the length of the crystals. Magnificent groups of prismatic crystals from Japan are known; and very good specimens are abundant at Felsöbanya, in Hungary, this being the locality of the specimen represented in Fig. 2, and also of that shown in Plate 20, Fig. 1, where the needles of stibnite are associated with crystals of barytes.

The colour of the mineral is steel-grey and the lustre metallic, but on exposure to light the surface gradually becomes dulled with a bluish or blackish tarnish. The mineral is quite soft (hardness = 2), and the crystals are easily damaged, unless handled with care.

Metallic antimony, which for the most part is obtained from the mineral stibnite, is much used for making alloys. For example, type-metal as used in printing is an alloy of four parts of lead with one of antimony. Salts of antimony find an application in medicine, and as pigments. Stibnite is used in the East for darkening the eyebrows, and it was also used by the ancients for the same purpose.

Realgar (Plate 4, Figs. 3 and 4).—Two distinct sulphides of arsenic occur in nature as minerals; they differ not only in the proportions in which the arsenic and sulphur are chemically combined, but also in their external characters, the difference in colour being particularly striking. These two minerals—the bright red realgar and the bright yellow orpiment—frequently occur together, as is shown in the two pictures on Plate 4.

In realgar, each chemical molecule consists of one atom of arsenic and one atom of sulphur, the formula being AsS. This compound is found in nature as small, monoclinic crystals, with an aurora-red colour, and often with perfect transparency (Fig. 4). On exposure to light, these crystals undergo a remarkable change; after some time, in place of a brilliant crystal, we find a heap of yellow powder. This change is due to an absorption of oxygen from the air, with the production of the yellow sulphide (As_2S_3) and white arsenious oxide (As_2O_3). The latter is soluble in water, and, like all soluble arsenic compounds, it is extremely poisonous. It is, therefore, necessary to keep specimens of this mineral in the dark, otherwise they soon become spoilt.

Both the specimens represented on Plate 4 are from Hungary. In Fig. 3 the realgar is massive, and shows no crystalline form.

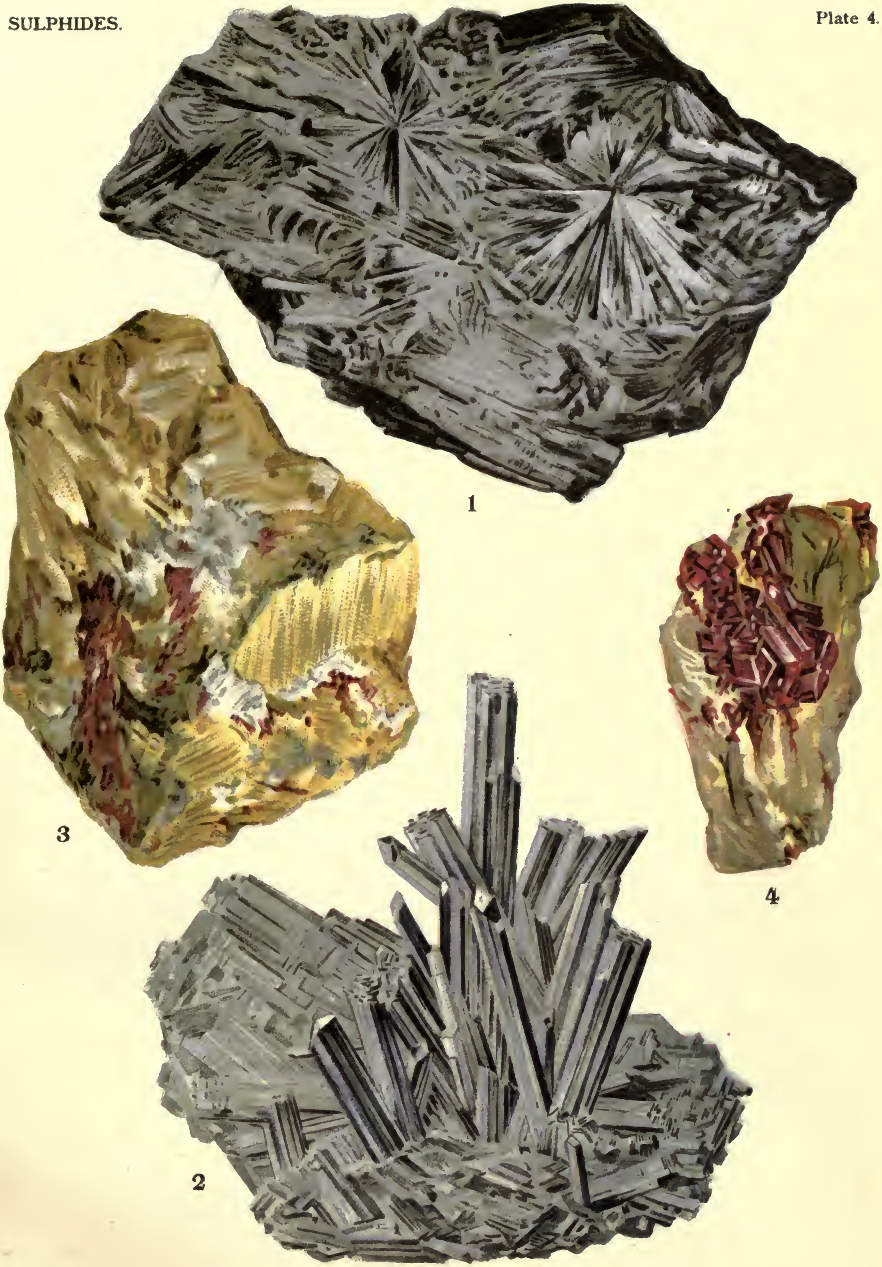
Orpiment (Plate 4, Figs. 3 and 4).—In the other native sulphide of arsenic, two atoms of arsenic are combined with three atoms of sulphur to form the chemical molecule, the formula here being As_2S_3, which is analogous to the formula of stibnite, with arsenic in place of antimony. The mineral also shows a relation to stibnite in its crystalline structure and perfect cleavage in one direction. It usually occurs as lamellar masses, distinctly developed crystals being extremely rare. The colour is bright lemon-yellow; and the bright, smooth cleavage surfaces have a pearly appearance. The name orpiment is a corruption of the Latin name *auripigmentum*, which means 'gold paint.' The pigment known as 'king's yellow' is, however, now prepared artificially.

Molybdenite (Plate 5, Fig. 1).—This mineral is the disulphide of the rare metal molybdenum, the chemical formula being MoS_2. It is found as platy or lamellar masses, and sometimes as six-sided plates or scales; but distinctly formed crystals are rare. It is opaque, with a metallic lustre and a lead-grey colour. The material is very soft (hardness = 1) and greasy to the touch, and it readily marks paper. This mineral presents, in fact, a most striking resemblance to graphite (p. 49), with which it is sometimes confused. There is, however, a slight difference in colour, which is noticeable when the two minerals are compared side by side, molybdenite showing a bluish tinge. In the specific gravity there is a very wide difference, the value for molybdenite being 4·7, and for graphite only 2·2. This affords a ready means of distinguishing the two minerals, and the difference in weight will be at once noticed if pure specimens of equal size are handled. When, however, a small amount of the mineral is embedded in a large piece of matrix, the specific gravity cannot be judged by merely handling the specimen. We may then detach a small scale of the mineral and drop it into a heavy liquid (such as bromoform, sp. gr. 2·8; or methylene iodide, sp. gr. 3·3); if the flake be molybdenite it will sink, whilst if it be graphite it will float on the surface of the liquid. The chemical behaviour also serves to distinguish the two minerals; when heated before the blowpipe, molybdenite gives a strong smell of burning sulphur.

Molybdenite is found as scales embedded in various crystalline rocks, such as gneiss and granite; and it is also met with in some metalliferous veins, more especially in veins of tin-ore. It is mined in Norway, Canada, and New South Wales.

The mineral is used to a small extent for the preparation of the molybdenum compounds used as reagents in the chemical laboratory. Within recent years it has been employed in the manufacture of steel; the addition of molybdenum gives a very tough and hard steel especially suitable for tools.

Zinc-blende (Plate 5, Fig. 2).—The sulphide of zinc (ZnS), known as zinc-blende, or simply as blende, is the most abundant of zinc-bearing minerals, and at the same time the most important ore of this metal.



1, 2, Stibnite. 3, 4, Realgar and Orpiment.

Crystals belong to the tetrahedral division of the cubic system, and their characteristic form is well shown in the picture (Fig. 2). Each of the three crystals here represented on the rocky matrix consists of a tetrahedron, the edges of which are truncated by narrow faces of the cube, and the corners are truncated by small faces of another (so-called negative) tetrahedron; in addition there are six small triangular faces symmetrically grouped round each of the corners. Although crystals of zinc-blende are of quite common occurrence, it is not often that their form can be so easily made out as in the example just mentioned. More usually the crystals are much distorted and the faces rounded, while frequent twinning still further adds to their complexity. A very important crystallographic character is the existence of perfect cleavages in six directions parallel to the faces of the rhombic-dodecahedron; the angles between adjacent cleavage surfaces is, therefore, 120° or 90°.

The faces of crystals and the cleavage surfaces are often very smooth and bright, and they display a characteristic resinous to adamantine lustre. The colour and transparency range between wide limits — from almost colourless and transparent to jet-black and opaque. Most commonly the mineral is dark yellow or brown and translucent, as represented in the picture. The mineral is thus very variable in its appearance, and this, together with the usually obscure crystalline form, makes its identification sometimes a matter of difficulty. Indeed, the old German word *blende* means to deceive, and the scientific name sphalerite, derived from the Greek, has the same signification. The miners' names 'black jack' and 'false lead' also indicate that the mineral was often mistaken for lead-ore.

As a help towards identifying the mineral, it should be scratched across a bright cleavage surface with a knife (having a hardness of rather less than 4 it readily yields), when a brown powder will be obtained. This, in conjunction with the perfect cleavages and the adamantine lustre, will often serve to distinguish zinc-blende from other minerals it may resemble in appearance. But as a confirmatory test, the mineral should also be examined before the blowpipe. For this purpose a small quantity of the powdered mineral is mixed with sodium carbonate and heated on charcoal in a reducing flame; the sublimate so obtained on the charcoal is yellow when hot and white when cold, and if it be moistened with cobalt nitrate solution and again heated it becomes bright green, indicating the presence of zinc.

When chemically pure, zinc-blende contains 67 per cent. of zinc, but frequently iron is also present to the extent of 1 or 2 per cent., or even as much as 18 per cent. It is owing to the presence of this variable amount of iron that the mineral varies so widely in colour and transparency. The specific gravity of 4·0 is much lower than that of the lead-ore (galena, sp. gr. 7·5), with which zinc-blende is so often associated; and advantage is taken of this difference in the methods employed for the separation of the two minerals from the ore.

Besides occurring as crystals, zinc-blende is abundant as granular or compact masses, but in such masses the bright cleavage surfaces may still be recognised.

Zinc-blende occurs in metalliferous veins, together with galena, calcite, fluor-spar, &c., and these veins often traverse limestone rocks. Good crystallised specimens are found at many localities. The specimen represented in the picture (Fig. 2) is from the Binnenthal, in Switzerland, where small crystals usually occur singly in cavities of a white, granular dolomite.

As an ore of zinc this mineral is mined in Cumberland, Wales, Germany, Missouri, and many other localities. Metallic zinc is largely used for galvanising iron, making alloys (brass, &c.), and in the construction of galvanic batteries. Its salts are used in dyeing and in medicine.

Galena (Plate 5, Figs. 3 and 4).—This is sulphide of lead (PbS), and a very important ore, containing 86·6 per cent. of the metal. Curiously, however, it is also of importance as an ore of silver, since galena almost invariably contains a minute proportion of silver, averaging about 0·03 per cent., or about 10 oz. of silver to the ton of galena. When the ore is smelted, this small amount of silver alloys with the metallic lead; and before the lead is sold for plumber's work the silver is extracted from it by a special process. Large amounts of silver have been obtained from the lead-roofing of old buildings by this modern process.

Good crystals of galena are quite common. They belong to the cubic system, and usually have the form of the cube, or of the cube combined with the octahedron. In the crystals represented on Plate 5, the predominating form is the octahedron, the corners of which are truncated by small faces of the cube. In Fig. 3 there are also narrow faces of an icositetrahedron (p. 11) replacing the edges between the cube and the octahedron; and in Fig. 4 the edges of the octahedron are truncated by narrow faces of the rhombic-dodecahedron.

The crystals can be split, or cleaved, with great ease parallel to the faces of the cube, and the surfaces of fracture are perfectly bright and smooth. These perfect cleavages in three directions at right angles are also shown by massive galena, on which no external crystal faces are present; and any lump of galena-ore when broken shows three sets of bright steps, whilst isolated fragments have quite the appearance of dice. This important character, taken in conjunction with the lead-grey colour and bright metallic lustre, makes galena easily recognisable at sight. The softness (hardness $= 2\frac{1}{2}$) and heaviness (sp. gr. 7·5) are also characters of importance. The mineral is opaque, and its streak is lead-grey.

Galena commonly occurs in metalliferous veins intersecting limestone rocks, and is often associated with zinc-blende, quartz, calcite, fluor-spar, &c. It is of wide distribution, and is mined in many parts of the world; for instance, in Derbyshire, County Durham, Lanarkshire, Spain, Germany, and the United States. The two specimens represented in Plate 5 are from Neudorf, in the Harz Mountains; here the crystals are associated with small rhombohedra of chalybite (iron carbonate) on a base of quartz.

Niccolite (Plate 6, Fig. 1).—A name very often misapplied to this mineral is 'copper-nickel,' from the old German name 'Kupfernickel;' but, although the mineral has a very characteristic copper-red colour, it contains no copper. It is, in fact, an arsenide of nickel ($NiAs$). Crystals are very rare, and the mineral is usually found as compact masses. It is brittle and breaks with an irregular fracture. This character, together with its greater hardness ($5\frac{1}{2}$) and black streak, is sufficient to distinguish it from native copper, which in colour it so closely resembles.

Niccolite is found, together with ores of silver, cobalt, and copper, at several places in Germany, and it has also been met with in Cornwall and Scotland. The specimen figured is from the copper-mining district of Mansfeld, in Prussia. Here the mineral was formerly used for the extraction of nickel, and also as a source of arsenic; but most of the nickel of commerce is now obtained from pyrrhotite (p. 73) and a silicate of nickel.

Cinnabar (Plate 6, Figs. 2 and 3).—This is sulphide of mercury (HgS), and is of importance as being the only ore of mercury, or quicksilver. This remarkable metal, which at the ordinary temperature is a liquid $13\frac{1}{2}$ times as heavy as water, is also found in the native state, though only in small amount, so that it is not a mineral of any economic importance. It is often to be seen on specimens of cinnabar, to the easy decomposition of which mineral it owes its origin. The silver-white spots on the upper portion of Fig. 3 represent small liquid globules of native mercury.

Crystals of cinnabar are not very common, and are mostly quite small. Large, well-shaped rhombohedra have, however, recently come from the cinnabar-mines in central China; these crystals usually consist of two interpenetrating rhombohedra intergrown in twinned position. The crystals have perfect cleavages parallel to the six faces of the hexagonal prism. They are often transparent, with a deep-red colour and brilliant lustre. On the darker crystals the lustre is quite metallic in character, especially when the full blaze of reflected light is observed from one of the crystal faces (Fig. 2).

The crystals are quite soft (hardness = 2), and when scratched they yield a scarlet powder. This is the characteristic colour of the mineral in its granular or earthy condition as commonly seen in the ore. In Fig. 2 there is shown a single crystal of cinnabar on massive cinnabar; and in Fig. 3 the massive mineral is scattered through the rocky matrix, which contains also yellow specks of iron-pyrites. Sometimes the ore is dark brown or black, owing to the admixture of clay or carbonaceous material.

Veins of mercury-ore are rather sporadic in their distribution, and mines are worked at but few places, notably Almaden in Spain, Idria in Carniola, and New Almaden in California. No mineral containing mercury has ever been found in the British Isles.

Mispickel (Plate 6, Fig. 4).—This mineral, which is also known as arsenopyrite, or arsenical pyrites, is a compound of iron, arsenic, and sulphur in equal atomic proportions, the formula being FeAsS. It is thus, at the same time, a sulphide and an arsenide, and may be described as a sulpharsenide of iron.

Crystals of mispickel belong to the orthorhombic system. Their characteristic rhombic form is clearly shown in the picture; here we have a short rhombic (four-sided) prism terminated at either end by a pair of dome faces like the roof of a house. Usually the prism faces are longer, and the crystals are then prismatic in habit. Columnar and granular aggregates of massive mispickel are also of common occurrence.

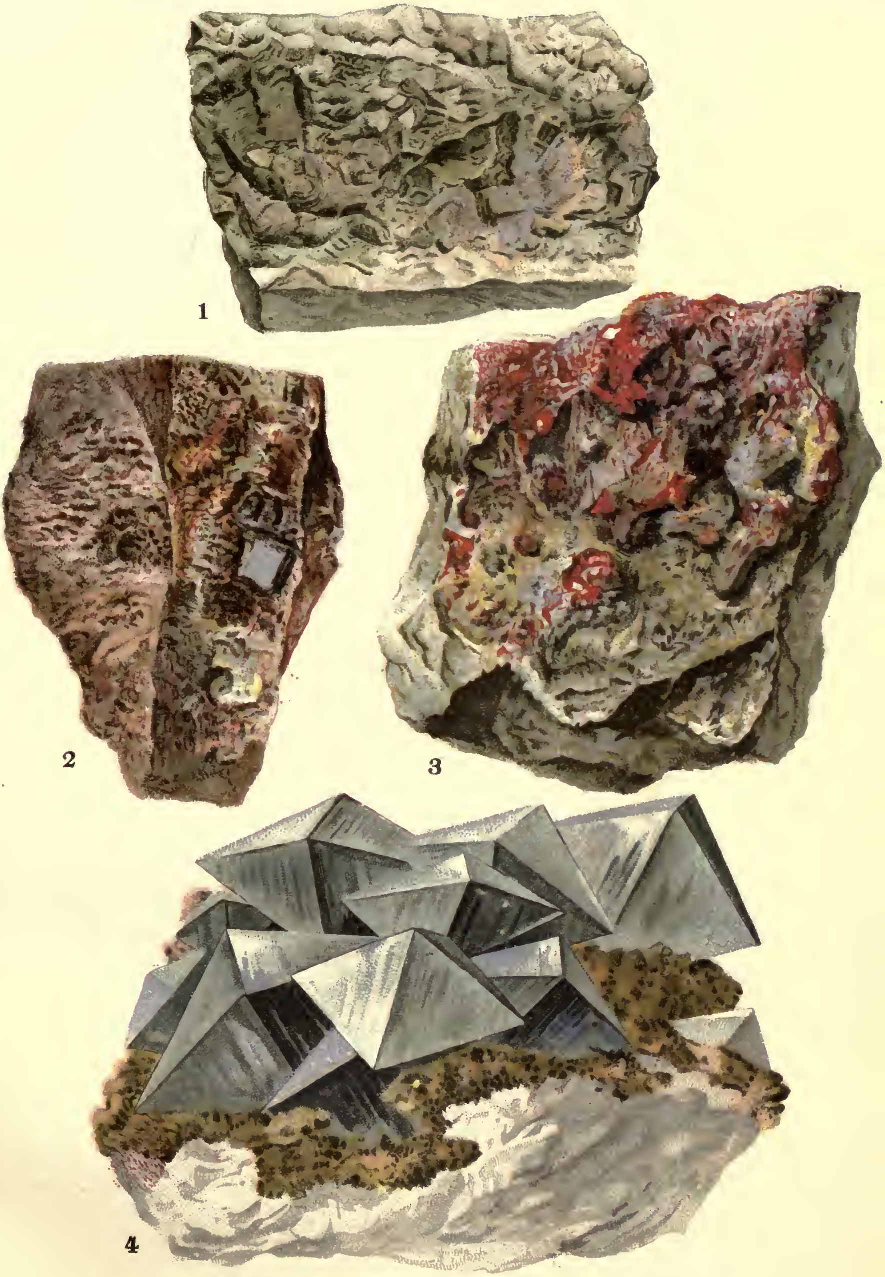
The mineral is tin-white, with a metallic lustre, but it often shows a bluish (Fig. 4), yellowish, or blackish tarnish. The specific gravity is 6; and the hardness is also 6, so that the mineral can be scratched with a knife only with difficulty.

Mispickel occurs in metalliferous veins, with ores of silver, copper, or tin. It is abundant in Cornwall and Devon, and at Freiberg, in Saxony. The specimen represented in Fig. 4 is from the latter locality; the large crystals rest with minutely crystallised chalybite on a bed of quartz.

This mineral is of importance in being the principal source of the extremely poisonous arsenious oxide (As_2O_3), or 'white arsenic,' which is obtained by simply roasting the ore in a current of air.

A variety of mispickel, in which a part of the iron is replaced by an equivalent amount of cobalt (5 to 10 per cent.), is called *danaite*, in honour of the famous American mineralogist, whose several books have long been standard works in this branch of science.

Marcasite (Plate 7, Fig. 1).—This is disulphide of iron (FeS_2), like the more common mineral iron-pyrites to be next described. These two minerals, although identical in chemical composition, are quite distinct in their crystalline form and physical characters. We have here another



1, Niccolite. 2, 3, Cinnabar. 4, Mispickel.

example of dimorphism, just as with the two crystalline forms of carbon (p. 49).

Marcasite also shows a relation to mispickel, the mineral last considered, in that the type of crystallisation is the same and the angles between the faces almost identical. Further, if we consider one of the atoms of sulphur in the marcasite formula to be replaced by one atom of arsenic, we arrive at the formula of mispickel. The two minerals mispickel and marcasite are, therefore, said to be isomorphous, meaning, in Greek, of the same form.

The form of marcasite crystals is, however, very often obscured by twinning, and we have complex groups of crystals to which the names 'cockscomb-pyrites' and 'spear-pyrites' are applied. The five-sided crystal shown in Fig. 1 really consists of five crystals united together by twinning; the striated faces correspond to the similarly striated dome faces of mispickel.

The colour of marcasite is pale brass-yellow, with a metallic lustre, but it is often obscured by surface tarnish and alteration. This mineral is, indeed, particularly liable to alteration by weathering, the sulphur being removed as sulphuric acid and the iron remaining behind as hydrated oxide of iron, which still preserves the original form of the crystals. Thus the brassy-looking marcasite comes to be replaced by the rusty brown limonite. The specific gravity (4·8) of marcasite is slightly less than that of iron-pyrites, and the hardness is much the same in the two minerals. The colour of marcasite is usually rather paler than that of iron-pyrites.

When distinctly formed crystals are not to be observed, as in the commonly occurring nodular masses with internal radiating structure, it is often extremely difficult, and in some cases impossible, to distinguish between marcasite and iron-pyrites.

Though not an uncommon mineral, marcasite is far less abundant and less widely distributed than is iron-pyrites. It is found in metalliferous veins in Derbyshire and Cornwall, and in beds of brown coal in Bohemia. The specimen represented in Plate 7 is from Dover, in Kent, and shows one larger and several smaller crystals embedded in a matrix of chalk. When found in sufficiently large amounts, marcasite is used for the same purposes as iron-pyrites.

Iron-pyrites (Plate 7, Figs. 2 and 3).—As already mentioned, this is disulphide of iron (FeS_2), identical in chemical composition with marcasite. The names pyrites and pyrite are also in common use for this species. It is one of the most widely distributed of minerals, being not only abundant in metalliferous veins, but found also as crystals embedded in rocks of all kinds, whilst sometimes it forms enormous bedded deposits.

Crystals are very common, and they usually have the form of small cubes (Fig. 2). On a critical inspection, it will be seen that these cubes differ from the cubes in which most other minerals crystallise; their faces are each striated parallel to only one edge, and the striations on adjacent faces are at right angles to one another. The system of crystallisation, though cubic, is of a lower (pentagonal-dodecahedral) type of symmetry. The pentagonal-dodecahedron is also a common form of crystals of iron-pyrites (Fig. 3); this solid is bounded by twelve five-sided faces (which are, however, not regular pentagons). The faces of this form are also striated on the same plan in three directions at right angles—namely, parallel to the cubic axes of the crystal, as is clearly shown in Fig. 3.

The colour both of the crystals and of compact masses is pale brass-yellow, with a bright metallic lustre; but the powder or streak of the mineral is dark greenish-black or brownish-black. The mineral shows no cleavage; it is brittle and breaks with an irregular fracture. The specific gravity is 5, and the hardness 6. It can scarcely be scratched with a knife; and when struck with steel it gives sparks, due to the burning of the sulphur in the detached fragments. Iron-pyrites was formerly used in tinder-boxes and firearms, and, indeed, the Greek word *pyrites* means 'fire stone.' These characters at once serve to distinguish iron-pyrites from native gold, for which it may possibly be mistaken.

Like marcasite, iron-pyrites is readily altered by weathering; and pseudomorphs of limonite (hydrated oxide of iron) with the form of crystals of iron-pyrites are not at all uncommon.

Iron-pyrites often contain small amounts of copper, gold, and other metals. The large deposits which are extensively worked at Rio Tinto in the south of Spain, in Norway, and in the Harz Mountains, contain on the average 3 per cent. of copper; but this may be accounted for by the admixture of copper-pyrites with the iron-pyrites. Such ores are roasted in a current of air to yield sulphur dioxide for the manufacture of sulphuric acid (oil of vitriol), and the residue is then treated for the extraction of the copper and traces of gold.

Good crystallised specimens of iron-pyrites are found at many places, amongst which may be mentioned the iron (magnetite) mines of Traversella, in Piedmont, Italy, and the iron (hæmatite) mines of Rio, in the island of Elba. The specimen represented in Plate 7, Fig 3, is from the latter locality, and shows the crystals of iron-pyrites on hæmatite; that in Fig 2 is from Cornwall.

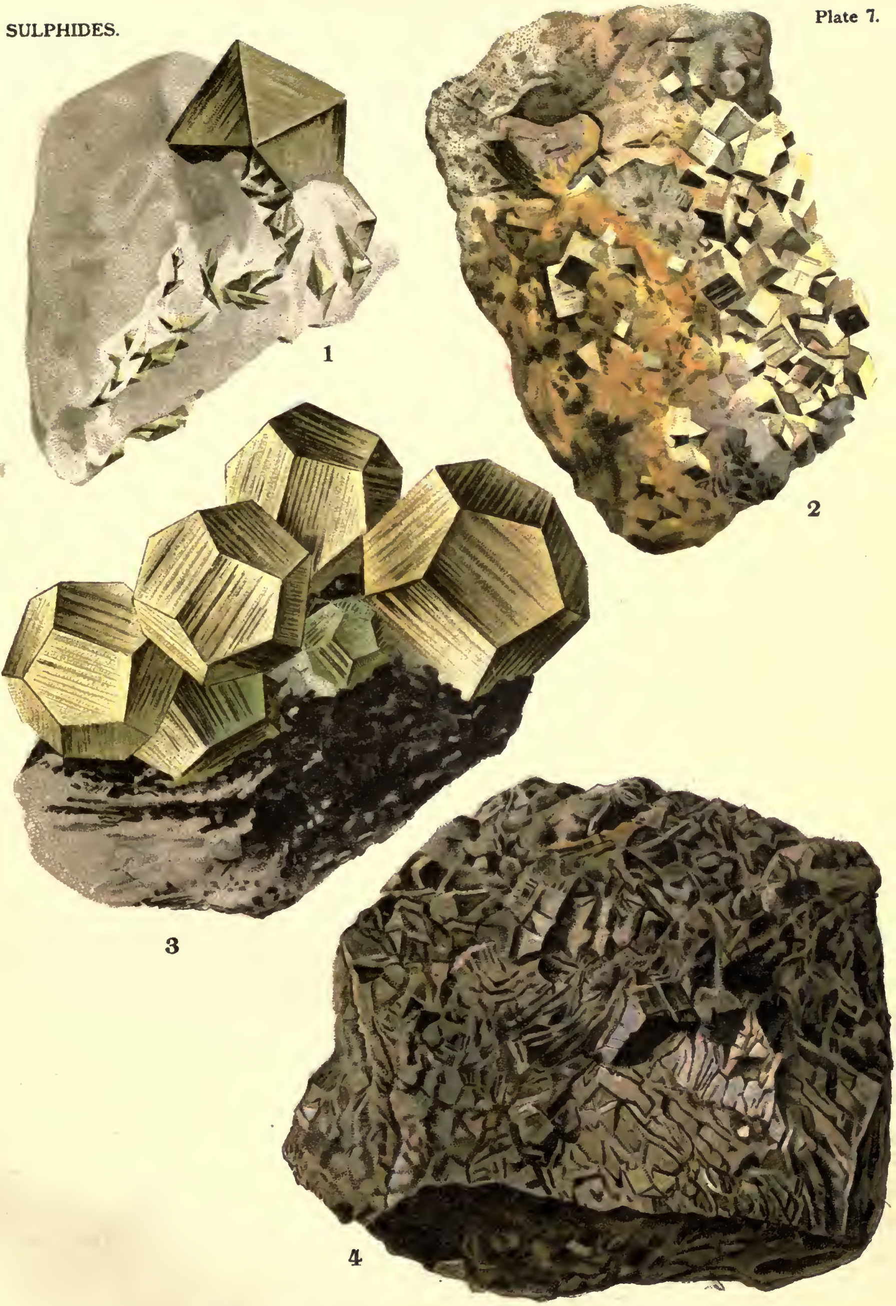
Pyrrhotite (Plate 7, Fig. 4).—Pyrrhotite, or magnetic pyrites, is another sulphide of iron, but one approximating in composition to the monosulphide FeS. Hexagonal crystals of platy habit are rare, and usually only compact masses (Fig. 4) are found. The colour is bronze-yellow tarnishing to brown, while the metallic lustre is usually dull. The mineral is rather softer (hardness = 4) than iron-pyrites, and it also differs from this in its magnetic character, small fragments being attracted by a magnet.

Pyrrhotite occurs as grains, embedded in certain igneous rocks, such as gabbro, and sometimes it is concentrated towards the margins of the rock-mass, forming workable deposits of ore. It is also found in metalliferous veins. The ore sometimes contains a small amount of nickel (3 to 5 per cent.), as in the large deposits at Sudbury in Ontario, and in Norway, where it is largely worked for the nickel. The specimen shown in Plate 7 is from Bodenmais, in Bavaria.

Copper-pyrites (Plate 8, Figs. 1 and 2).—Copper-pyrites, or chalcopyrite, is a sulphide of iron and copper, with the formula $CuFeS_2$, and contains, when pure, 34½ per cent. of copper and 30½ per cent. of iron. It is the most abundant of copper minerals, and at the same time the most important ore of copper.

Crystals of copper-pyrites belong to the tetragonal system; they are usually small and indistinct, and it is not often that their form can be easily deciphered; often the form approximates to an octahedron (Fig. 2) or tetrahedron. Compact masses are much more common.

This mineral closely resembles iron-pyrites in general appearance; it differs, however, in its darker brass-yellow colour and in its lower degree of hardness (H. = 4). Copper-pyrites can readily be scratched with a knife, giving a dark, greenish-black streak, whilst iron-pyrites is scratched only with difficulty. In case of doubt, a confirmatory test should be made by dissolving a little of the powdered mineral in nitric acid, when the presence of copper will be indicated by the green colour of the solution. On the addition of a large quantity of ammonia to this solution the green colour changes



1, Marcasite. 2, 3, Iron-pyrites. 4, Pyrrhotite.

to blue, and the iron is thrown down as a bulky reddish-brown precipitate.

The surface of massive copper-pyrites very often displays brilliant iridescent colours, such as intense red, blue, or golden yellow, which, combined with the metallic lustre, give the mineral a very striking appearance. On this account it is called 'peacock-ore' by the miners. These iridescent colours are due to an extremely thin film of some alteration product on the surface of the copper-pyrites.

This mineral is found in metalliferous veins, and especially those near the junction of granite and slates; associated minerals are zinc-blende, quartz, chalybite, &c. It also forms masses in igneous rocks, as in Tuscany; or beds in sedimentary rocks, as in Thuringia. The crystallised specimens shown in Plate 8 are from Cornwall (Fig. 1, on quartz), and Freiberg, Saxony (Fig. 2).

Smaltite (Plate 8, Fig. 3).—This important ore of cobalt is an arsenide of cobalt, $CoAs_2$, but it also contains variable amounts of iron and nickel.

The crystals are cubic, but are rare, and never very sharply developed. In Fig. 3 is shown a confused group of cubes, with rounded surfaces, and the corners truncated by small triangular faces of the octahedron. Granular and compact masses are more usual. The colour is steel-grey, with a metallic lustre.

The presence of cobalt in this mineral is very often betrayed by the occurrence of crimson specks and patches of earthy erythrite, or cobalt-bloom, on the surface of the specimens. This is a hydrated arsenate of cobalt, formed by the weathering of the smaltite. Similarly, on the surface of chloanthite ($NiAs_2$)—a mineral closely allied to and very similar in appearance to smaltite, but differing from it in containing nickel in place of cobalt—there may very often be detected patches of earthy, apple-green annabergite, or nickel-bloom. Indeed, the presence of these alteration products affords a ready means of recognising these minerals.

Smaltite occurs in metalliferous veins, together with ores of silver; it is found at several places in Germany, notably at Schneeberg, in Saxony, this being the locality of the specimen represented in Plate 8. Recently, large quantities of the mineral have been found at Cobalt City, near Lake Temiskaming, in Ontario. This ore of cobalt is principally used for the preparation of smalt (hence the name smaltite), or cobalt-blue, which is employed as a pigment and for colouring glass and porcelain.

Tetrahedrite (Plate 8, Fig. 4).—Other names for this mineral are grey-copper-ore and fahlore (German, *Fahlerz*). Ideally, it is a compound of copper, antimony, and sulphur—that is, a sulph-antimonite of copper, with the formula Cu_3SbS_3. Actually, however, the copper may be in part replaced by silver, iron, zinc, mercury, &c., and the antimony by arsenic. In certain mining districts it is an important ore of copper; but when silver is also present (sometimes to the extent of 30 per cent.), it is of far greater importance as an ore of silver, and many of the rich Bolivian silver-ores are of this type.

Its crystals belong to the tetrahedral division of the cubic system, the name tetrahedrite referring, in fact, to their characteristic tetrahedral habit (Fig. 4). In this picture the predominating form of the two crystals, shown attached to the matrix, is a three-faced tetrahedron; the acute corners are each replaced by three small faces of the rhombic-dodecahedron, and the edges are truncated by narrow faces of a deltoid-dodecahedron.

The colour is iron-black or steel-grey, and the lustre metallic. Sometimes, however, the crystals have a thin coating of copper-pyrites on their surface, having then the appearance of a brassy-yellow mineral. Fine crystals of this kind, often with a brilliant iridescent tarnish on their surface, were formerly found in Herodsfoot mine, Cornwall. Other localities for well-crystallised specimens are in the Harz Mountains (Fig. 4), and Kapnik, in Hungary.

Pyrargyrite (Plate 8, Fig. 5).—This mineral is also known as dark-red silver-ore, or as ruby-silver; and containing 60 per cent. of silver, it is a rich ore of this metal. It is a compound of silver, antimony, and sulphur—that is, a sulph-antimonite of silver, with the formula Ag_3SbS_3.

The crystals are rhombohedral, and usually consist of a hexagonal prism, terminated by a flat rhombohedron (as shown in Fig. 6 for proustite); in Fig. 5 the hexagonal prism is terminated by large faces of a scalenohedron, with small faces of the rhombohedron at the apex, the form here being the same as in calcite (Plate 16, Fig. 1).

The colour seen on the surface of the crystals is greyish-black, but small crystals and fragments are deep ruby-red by transmitted light; and the same ruby-red colour is also to be seen on portions of the crystals that are bruised or fractured. The colour of the streak, or of the powdered mineral, is purplish-red.

Pyrargyrite is found in veins of silver-ore at Andreasberg, in the Harz Mountains; at Freiberg, in Saxony; and at Guanajuato, in Mexico.

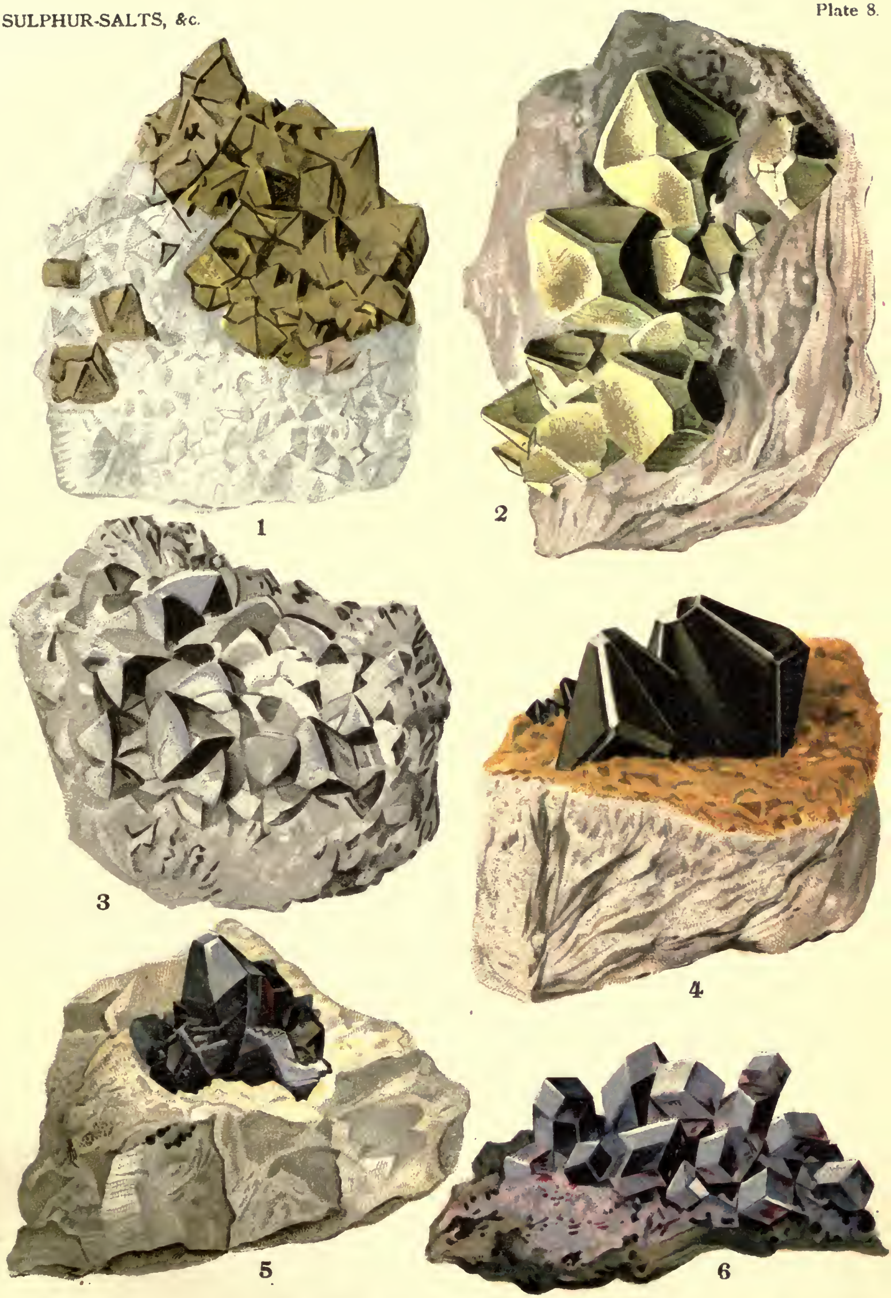
Proustite (Plate 8, Fig. 6).—This is another ruby silver-ore, known as light-red silver-ore, which differs from the last in containing arsenic in place of antimony, the chemical formula being Ag_3AsS_3. The pure mineral contains 65½ per cent. of silver. The crystals are of the same type as those of pyrargyrite, though the scalenohedral habit (Fig. 5) is more characteristic of proustite than the prismatic habit (Fig. 6). The crystals are transparent, with a magnificent ruby-red colour; but on exposure to light they very soon blacken and became opaque. For this reason specimens must be kept in the dark. The colour of the streak is scarlet.

This difference in the colour of the streak affords a ready means of distinguishing pyrargyrite and proustite, which are often confused. Indeed, it seems probable that Figs. 5 and 6 of Plate 8 have been accidentally interchanged, as suggested by the habit of the crystals.

Magnificent groups of transparent ruby-red crystals of proustite are found in the silver-mines at Chañarcillo, in Chile, and good specimens are also known from Freiberg, in Saxony.

SULPHUR-SALTS, &c.

Plate 8.



1, 2, Copper-pyrites. 3, Smaltite. 4, Tetrahedrite. 5, Pyrargyrite. 6, Proustite

CHAPTER VII.

The Haloids.

The chemical elements fluorine, chlorine, bromine, and iodine are known collectively as halogens, and the compounds, or salts, formed by their union with a metal are known as haloids. This word is derived from the Greek name for salt—that is, common salt or rock-salt, which may be taken as the type of this group.

Only a small number of minerals fall into this group, and most of them are quite rare and not suitable for illustration in colour. To the descriptions of the three species figured in Plates 8 and 9, we shall add a brief mention of one or two others which present certain points of interest.

In their general appearance and external characters the different minerals of this group have little in common, though they are all transparent to a greater or less degree. In colour they exhibit a wide range, and their practical applications are equally diverse.

Fluor-spar (Plate 9, Figs. 1 and 2).—Fluor, or fluorite, is a beautiful mineral, presenting many points of interest. It is of fairly wide distribution, and in certain districts it is found in enormous quantities in association with lead-ore.

Chemically, it is a fluoride of calcium (CaF_2), being a compound of the extremely active gas fluorine with the metal calcium. It is insoluble in water, and is very resistant to most chemical reagents; but when warmed with sulphuric acid, it is decomposed with the liberation of hydrofluoric acid gas. This gas readily attacks glass and other silicates, and on this action depends its use for etching glass. Fluor-spar fuses at a red-heat, and on this account it is employed as a flux in the smelting of ores. For this reason, the mineral takes its name from the Latin *fluo*, I flow.

Good crystallised specimens are common. The crystals belong to the cubic system, and most frequently have the form of perfect cubes (Plate 9). On specimens from certain localities the edges of the cube are sometimes each bevelled by two narrow faces of a form known as a four-faced cube; or again, the corners may be each replaced by six small faces of a six-faced octahedron; but these modifications of the cube are comparatively rare. Another, but far less common form, is the simple octahedron, as in the beautiful pink octahedra of fluor-spar from Chamounix and a few other places in the Alps.

Very frequently the crystals are twinned; there being an intergrowth or interpenetration of two cubes, with the result that the corners of one cube project from the faces of the other. The two cubes are related to one another in a perfectly regular geometrical manner; one of the diagonals joining opposite corners of the cube is common to the two cubes; and if one of the cubes be rotated about this diagonal as axis through half a complete revolution, it will come into a position coincident with the second cube. This peculiar twin intergrowth is an extremely characteristic feature of fluor-spar.

Another very important character of this mineral is its perfect octahedral cleavage—that is, the crystals may be split with ease along four plane directions parallel to the faces of the octahedron. For this reason specimens of fluor-spar are very liable to be damaged by having the projecting corners of the cubes knocked off. Thus, in Plate 9, Fig. 1, some of the corners of the cubes are replaced by small triangular cleavage surfaces. In the same specimen may be seen cleavage cracks in the interior of the crystals, with the cracks intersecting the cube faces parallel to the diagonals of the latter.

The faces of the crystals and of the cleavage surfaces are usually very bright and smooth, with a lustre like that of glass. Fluor-spar can be readily scratched with a knife; and it is very brittle. Its specific gravity is 3·2.

The range of colours shown by fluor-spar is very extensive, and, indeed, no other mineral affords so good an example of how colour may vary in one and the same species. When quite pure, fluor-spar is perfectly colourless and transparent. The mineral may also show delicate or intense shades of blue, purple (Fig. 1), green (Fig. 2), pink, yellow, or sometimes even black. Frequently also the same crystal may be of different colours in layers parallel to the cube faces. The well-known 'blue-john' of Derbyshire is a dark purplish, fibrous variety of fluor-spar. These colours are due to the presence of mere traces of colouring matter, so small in amount that the exact nature of the pigment is still a matter for discussion. The fact that in many cases the colour is destroyed by heat—the fluor-spar becoming quite colourless—suggests that the colouring matter is a hydrocarbon of some kind. Certain specimens are changed in colour on exposure to sunlight; for example, green may be changed to purple.

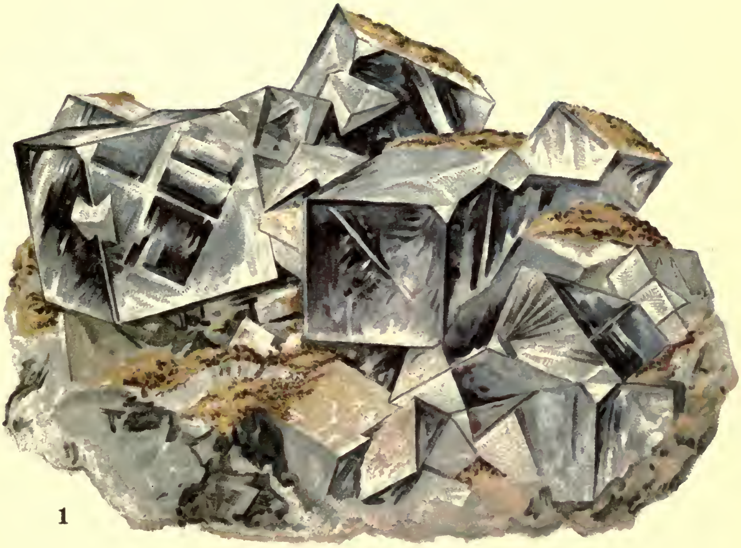
A remarkable property exhibited by some crystals of fluor-spar—particularly those from the north of England—is that they show one colour by transmitted light, and another colour by reflected light. The crystals like those represented in Fig. 1, if held between the observer's eye and the window, appear pale green; but if the eye be between the specimen and the window, a rich velvety, plum-blue colour is to be seen on the surfaces of the crystals. This phenomenon, having been first recognised in fluor-spar, is known as fluorescence. Another interesting property, of a somewhat similar optical nature, is that of phosphorescence. When fluor-spar is heated to a temperature below red-heat it glows with a soft greenish light, like that of the glow-worm.

Fluor-spar occurs in nature under a variety of conditions. It is found in granite, and in veins of tin-ore, in Cornwall; in gneiss in the Alps; in limestone, and in veins of lead-ore, in Derbyshire and the north of England; and rarely in the lava of Vesuvius.

The best-crystallised specimens are those found abundantly in the lead-mines of the north of England, in Cumberland, Northumberland, and more particularly in County Durham. In Weardale (County Durham) large cavities completely lined with beautiful crystals, measuring sometimes as much as twelve inches or even more along the edges of the cubes, are not uncommonly met with. The two specimens represented in Plate 9 are from Weardale; in Fig. 1 the crystals are partly encrusted with chalybite, and in Fig. 2 they rest on a base of iron-stone.

Some of the practical uses of fluor-spar have already been briefly mentioned. Large quantities — thousands of tons annually—are mined in Derbyshire and the north of England for use as a flux in smelting ores. The mineral is also used for the preparation of hydrofluoric acid and for etching glass, and in the manufacture of opaline glass. Perfectly colourless and transparent crystals find an application in the construction of lenses for microscopes; while the Derbyshire 'blue-john' is carved into vases and other small ornaments. The finer-coloured crystals have occasionally been cut as gem-stones, but the low degree of hardness of the mineral renders it unsuitable for use in jewellery.

Rock-salt (Plate 10, Figs. 1 and 2).—Salt, or common salt, is a mineral of great importance in everyday life. To the mineralogist it is known as rock-salt, or halite (from the Greek name for salt). The reddish-brown lumps of salt given to cattle to lick is rock-salt in the condition in which it is found in the earth. This may be readily purified by dissolving it in water and allowing the earthy impurities to settle;



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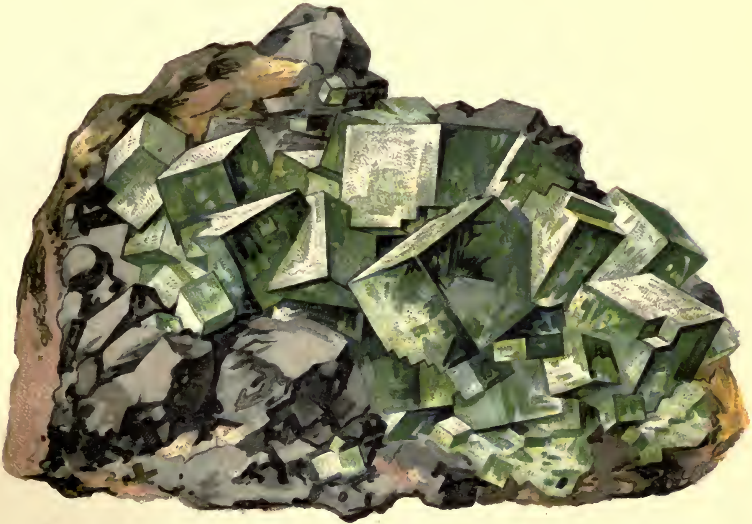

2

1, 2, Fluor-spar.

on evaporating the clear solution, the pure white table-salt or cooking-salt is obtained. It may be remarked in passing that very few minerals are soluble in water; the only one described in this book being the one under discussion.

Salt is deposited by the evaporation of sea-water in land-barred gulfs and from the salt water of inland lakes, such as the Dead Sea and the Great Salt Lake of Utah. Such deposits may become covered up by layers of mud, and so protected and preserved. In this way beds of rock-salt, sometimes of enormous thickness, have been formed in past epochs of the earth's history; and these are now found and mined in the sedimentary rocks of various geological periods. The beds of rock-salt for which Cheshire is famous are interstratified with the red marls and sandstones of Triassic age, while many of those in the United States are of considerably greater antiquity.

The rock-salt occurring in these beds is massive, and may be quite pure, being then white or colourless, or it may be somewhat intermixed with clay and red oxide of iron, when it is reddish-brown in colour. Cavities when present in this massive material are lined with crystals of rock-salt. Good crystals are, however, not common; the best come from Strassfurt, in Prussia (Plate 10, Fig. 1), and from Wieliczka, in Poland (Fig. 2).

Crystals of rock-salt belong to the cubic system, and almost invariably they have the form of simple cubes (Plate 10, Figs. 1 and 2). These crystals are thus of exactly the same form as those of fluor-spar, but there is a very important difference between them in their cleavage. Whilst in fluor-spar the perfect cleavages are parallel to the faces of the octahedron, in rock-salt they are parallel to the faces of the cube. A crystal of rock-salt may therefore be easily broken up into a number of smaller cubes, and this subdivision can be repeated indefinitely.

The crystals are usually perfectly colourless and transparent (Fig. 2), but occasionally they are of a deep blue colour. The cause of this blue colour is very mysterious, for the colour disappears when the salt is dissolved in water or when it is heated; further, a similar colour is induced in colourless rock-salt by heating it in the vapour of metallic sodium.

Beds of rock-salt are sometimes worked by the ordinary methods of mining, but more frequently water is admitted through bore-holes into the salt-bearing strata and the solution of salt pumped up. Large quantities of salt are also yielded by natural salt springs and by the solar evaporation of sea-water in salt-pans. The famous mines of Wieliczka, near Cracow, which have been worked for the last 600 years, form a large subterranean town carved in the thick bed of solid rock-salt.

Some other modes of occurrence of rock-salt are of interest, though of no practical importance. The mineral is sometimes to be found as an encrustation on Vesuvian lava; and in the extremely minute cavities in the quartz of many granites, cubes of rock-salt immersed in a liquid may be seen under the higher powers of the microscope.

Atacamite (Plate 10, Fig. 3).—This is a rare copper mineral, though at one or two places it is found in sufficient abundance to be mined as an ore of copper. It is a combination of chloride of copper and hydroxide of copper, with the somewhat complex formula $CuCl_2.3Cu(OH)_2$. Its crystals are of a rich, deep-green colour, with a brilliant lustre; they have the form of rhombic prisms, with pyramidal terminations. Small but brilliant crystals are found in the Desert of Atacama (hence the name atacamite) and other parts of Chile; while larger crystals are abundant at Wallaroo, in South Australia. The specimen represented in the figure is from the latter locality.

Atacamite was put to a curious use before the days of blotting-paper, the powdered mineral being sprinkled over letters to dry up the ink. A sample of the 'writing sand' from Atacama was presented to the British Museum collection by the Abbé Rochon in the year 1790.

Cerargyrite, or Horn-silver.—Under this term are included several minerals which are compounds of silver with chlorine, bromine, and iodine. In Chile, Nevada, and New South Wales they are found in considerable quantity and are of importance as ores of silver. These minerals present a horn-like appearance, and like horn they can be cut with a knife. Their pale yellow or greenish colour quickly darkens on exposure to light. Their cubic crystals are small and obscure, and not suitable for illustration.

Cryolite.—This is the only other haloid that we need mention in this place. It is a fluoride of sodium and aluminium (Na_3AlF_6), and is of importance as an ore of metallic aluminium. It is a white or colourless mineral, with somewhat the appearance of ice, and for this reason it is known as ice-spar (the name cryolite having the same meaning in Greek). It is extensively mined at one spot in Greenland, and is employed in the manufacture of opal-glass and iron-enamel. Formerly metallic aluminium was extracted exclusively from cryolite, but now bauxite, together with a small proportion of cryolite, is employed.

CHAPTER VIII.

The Oxides.

This group of oxides, or compounds of oxygen with another chemical element, includes several important minerals, some of which are used as precious stones and others as ores of the metals.

Quartz (Plates 11 and 12).—Quartz is the most abundant and widely distributed of all minerals. The sand of the seashore consists almost entirely of grains of quartz; and when these are cemented together to form solid rock, we have the abundantly occurring sandstone. Various other kinds of rocks, such as granite and gneiss, also consist in part of quartz, and, indeed, the mineral is the most important of the rock-forming minerals. In the neighbourhood of London, and other places in the south-east of England, practically the only kind of stone to be found is flint, which is a compact variety of quartz.

Chemically, quartz is the dioxide of the non-metallic element silicon; this oxide is usually known simply as silica, and its formula is SiO_2.

Not only is quartz the most abundant of minerals, but it is one that appears in a greater variety of forms or guises than any other mineral. It may be either perfectly colourless and transparent like glass, or black and opaque like jet. Or, combined with varying degrees of transparency, it may be of all shades of colour from one end of the spectrum to the other—red, orange, yellow, green, rarely blue, and violet. Again, in the character of its lustre, it may be either glassy or waxy, or quite dull and earthy. Further, it may be crystallised in beautiful forms, or it may be compact with no obvious crystalline structure.

Owing to this great diversity in its external appearance, a considerable number of varieties of quartz are recognised and distinguished by special names—for example, rock-crystal, amethyst, jasper, carnelian, agate, onyx, flint, hornstone, and many others. These several varieties may be conveniently divided into two great groups—namely, crystallised quartz and crypto-crystalline (i.e. minutely crystalline) quartz, which are illustrated on Plates 11 and 12 respectively.

Quartz is thus a mineral not always easy to recognise. Characters of the first importance which help in its determination are (1) the absence of cleavage, (2) the hardness, and (3) the specific gravity. The degree of hardness (No. 7 on the scale) is such that the mineral cannot be scratched with a knife, and when an attempt is made to scratch it a metallic mark is left on the stone. It is, further, a comparatively light mineral (sp. gr. 2·65), being only about two and a half times as heavy as an equal volume of water. If, therefore, we have a stone, consisting to all appearances of the same kind of material throughout, which is not heavy, cannot be scratched with a knife, and shows no trace of cleavage, we are fairly safe in pronouncing that it consists of the very common mineral quartz. By way of confirmation, we may determine whether a fragment of the stone remains suspended together with a known crystal of quartz in a heavy liquid (such as a mixture of methylene iodide and benzene; see p. 31) of suitable density.

If, however, the specimen is crystallised, there need not be the slightest hesitation in the determination, for crystals of quartz possess an extremely characteristic form. As clearly shown in Plate 11, Figs. 1–3, they consist of a hexagonal, or a regular six-sided, prism capped by a six-sided pyramid. In Fig. 2 the six pyramid faces are of equal size, but in Figs. 1 and 3 they are alternately larger and smaller, with a three-fold arrangement. Additional faces are sometimes, though rarely, present on crystals of quartz. On each of the three alternate corners between the prism and pyramid there may occasionally be a small rhomboidal face (Fig. 3), and sometimes also a small trapezoidal face (Fig. 2) between the latter and a prism face. In Fig. 2, this trapezoidal face is placed on the right-hand side of a prism face, and the crystal is, therefore, a right-handed crystal. We may also have left-handed crystals of quartz. Two such crystals, a right-handed and a left-handed, may be exactly alike, except that one is the mirror-reflection of the other, and like the right and left hands they cannot be brought into coincident positions.

A specially characteristic feature of crystals of quartz, and one which helps in the recognition of the mineral, is that the prism faces are always more or less deeply striated, or grooved, horizontally; that is, they are marked by fine lines perpendicular to the edge of the prism. In many other minerals which crystallise in prismatic forms—e.g. beryl and topaz—the prism faces are more usually striated parallel to the prism edges.

To proceed still further with the crystallography of quartz —about which, indeed, a whole volume might be written—it may be remarked that not only are the shapes of the crystals and the striations characteristic and peculiar to the mineral, but also the magnitude of the solid angles between the faces are equally characteristic and constant for the species. It was determined, so long ago as 1669, by Nicolaus Steno, a Danish physician, that the angle between adjacent prism faces is always exactly 120°, and that the angle between a prism face and a pyramid face is about 142° (more exactly 141° 47′ of arc). The angle of slope * of the pyramid faces to the horizontal is thus very nearly 52°, which curiously is

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* In Plate 11, Fig. 1, the crystals are not drawn quite correctly in this respect, the pyramid being rather too low.

the same as that of the Pyramids of Egypt. Again, at the top of the crystal the angle between alternate pyramid faces is 94° 14′, or nearly a right angle; so that, when three alternate faces are largely developed at the expense of the other three, the crystal may assume a cube-like aspect.

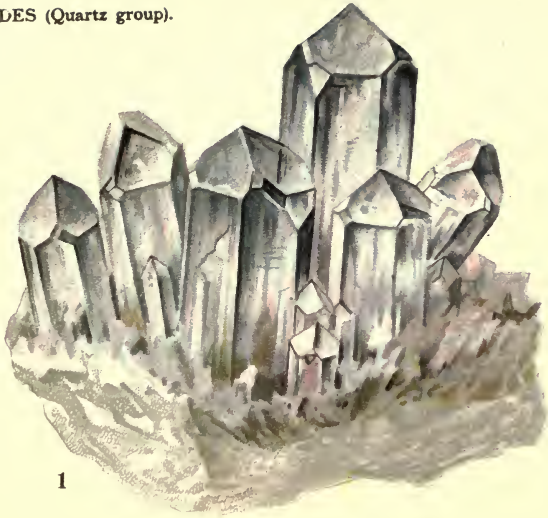
The shapes of the faces themselves are likewise characteristic, and the plane angles between their edges are also fixed in magnitude. The prism faces are rectangular in outline, with angles of 90°, and the striations on them are parallel to one pair of edges. The pyramid faces when equal in size (as in Fig. 2) have the shape of acute isosceles triangles, with angles of 70° at the base and 40° at the apex, and with the sides half as long again as the base. It will be found useful to bear these figures in mind. For quartz frequently occurs minutely crystallised in cavities and crevices, forming so-called drusy surfaces; and if such material be examined with a magnifying-glass, the characteristic shapes of the prism and pyramid faces can usually be distinguished when the tiny facets catch the light.

There being no cleavage, the fracture of quartz is typically conchoidal, and on the rounded, shell-like surfaces of fracture the lustre is bright and vitreous in character. A fractured surface of quartz presents exactly the appearance of broken glass. Amethyst shows on its fractured surface a very peculiar and characteristic appearance; it is marked with minute ripples or 'thumb-marks,' just like those formed when the thumb is pressed against some plastic substance.

Quartz when perfectly pure is quite transparent and colourless, this being the variety known as rock-crystal. The specimen represented in Plate 11, Fig. 3, is from the Swiss Alps. Such specimens were believed by the ancients to be ice, frozen so hard on the highest peaks of the Alps that it could not be again thawed. It is, indeed, owing to this belief that rock-crystal received its name, the word *krystallos* meaning in Greek 'clear ice.' In the seventeenth century this name came to be extended to the other plane-faced bodies which we now know collectively as crystals.

The distinction between other varieties of crystallised quartz depends solely on differences in colour. Clear yellow crystals are known as citrine, 'occidental topaz,' or 'false topaz;' and those of a more pronounced brown colour, as smoky-quartz (Plate 11, Fig. 2; representing a specimen from Switzerland) or cairngorm, after the locality in Scotland where such crystals are found. Amethyst (Fig. 1; from Brazil) is violet, or purple, crystallised quartz. Rose-quartz (Fig. 5; from Rabenstein, in Bavaria) is of a fine rose-red colour; this variety is, however, found only as broken masses, without crystal faces.

Another variety known as cat's-eye (Plate 11, Fig. 4; from Ceylon) owes its special appearance to the enclosure in the crystallised quartz of large numbers of very fine fibres of asbestos arranged parallel to each other; or sometimes the asbestos may have been dissolved out of the stone, leaving hollow canals. Such stones, especially when cut and polished with a convex surface (as represented in the picture), exhibit a milky band of reflected light, and, as the stone is moved about, this band travels across the surface. A fancied resemblance to the eye of a cat gives these stones their name of cat's-eyes, while the special optical effect is known as chatoyancy. Strictly, however, they should be called quartz cat's-eye, for the same effect may be shown by other minerals—for example, chrysoberyl, tourmaline, and gypsum—which may accidentally possess an internal fibrous structure. Quartz cat's-eyes are usually pale yellowish or greenish in colour, but those from the Asbestos Mountains, on the Orange River, in South Africa, display a magnificent golden-yellow sheen. The latter are known by the special name of tiger-eye, and often, OXIDES (Quartz group).



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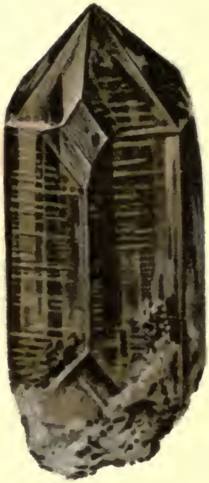

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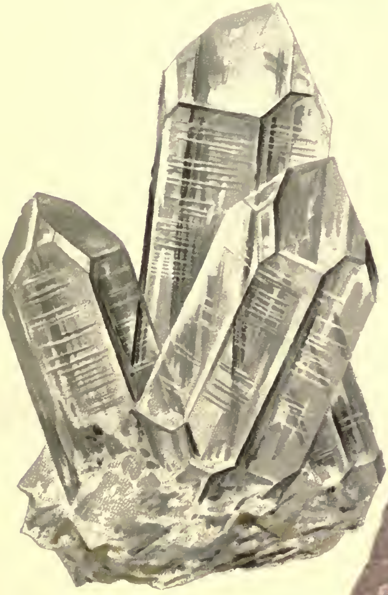

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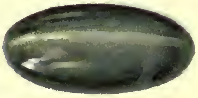

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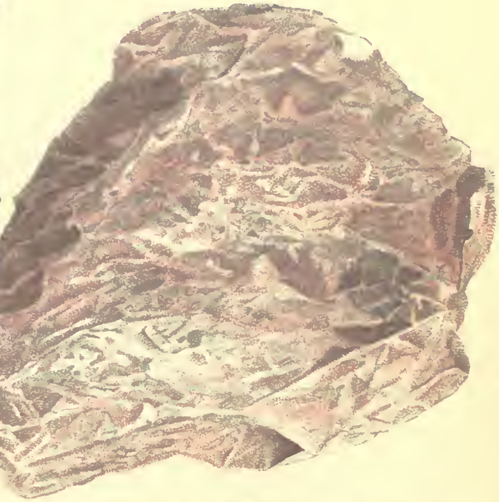

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1, Amethyst. 2, Smoky-quartz. 3, Rock-crystal. 4, Cat's-eye. 5, Rose-quartz.

erroneously, as crocidolite (compare the description of Plate 26, Fig. 3).

Coming now to the several varieties of crypto-crystalline or compact quartz, these consist not of single crystals, but of aggregates of vast numbers of minute crystalline individuals, or interlocking grains so closely crowded together that they have had no opportunity to develop crystal faces at their boundaries. The exact mode of aggregation may of course be varied, giving rise to a corresponding number of varieties distinguished by special names.

Jasper consists of such an aggregate, the minute grains of quartz being here much intermixed with clayey material and with red or yellow oxides and hydroxides of iron. These impurities give rise to the different colours (red, yellow, brown, green, blue), which may be present singly or together in the same piece of stone. When the arrangement of colours is in parallel bands, we have the variety called riband-jasper. In the red jasper shown in Plate 12, Fig. 3, the coloration is nearly uniform, while in the ball-jasper in Fig. 2 (from Freiburg, in Baden) there is a concentric banding of red and yellow. Hornstone (Fig. 4) is of much the same character, but with much less admixed impurity; it presents a certain amount of translucency, with dull greyish or brownish colours, so that it somewhat resembles horn in appearance. Its fracture is splintery.

Chalcedony is a rather special variety of crypto-crystalline quartz, in which the structure, as seen on a fractured surface, is minutely fibrous. On the surface it presents rounded (mamillated, botryoidal, and stalactitic) forms, with a semi-transparent appearance, and a lustre like that of wax. Here, again, we have several varieties depending on differences in colour and the arrangement of differently coloured portions. The colour of common chalcedony is white or creamy. When it is bright orange-red, we have the well-known carnelian; and when brown, the sard. Pale apple-green chalcedony is known as chrysoprase, and that of a dark leek-green colour as plasma. An interesting variety of a dark-green colour, marked with bright red spots, like drops of blood, is called bloodstone, or heliotrope. When it is banded and of different colours, the bands may be more or less concentric, as in agate (Plate 12, Fig. 1),* or straight, as in onyx. Again, we may have in chalcedony enclosures of colouring matter, bearing in their form some resemblance to moss and other plant-like, or dendritic, forms, as in moss-agate and mocha-stone.

As to the practical uses to which quartz is applied, these are extremely numerous. In the form of sandstone, it is much used for building and paving. Pure quartz-sand, the so-called silver-sand, is extensively used in the manufacture of glass, and also for abrasive purposes (sand-paper) and for scouring, being often mixed with soap. Clear rock-crystal is employed for the construction of prisms and lenses for optical purposes; it is the 'Brazilian pebble' of the spectacle-makers, though quartz is much less used now than formerly for spectacle-lenses. Recently fused quartz, or silica-glass, has been much used for the construction of various pieces of apparatus for the chemical laboratory.

Several varieties, especially those which are clear or of a fine colour, are extensively used in jewellery as semi-precious stones. Of these, amethyst is the most valuable; others whose names are familiar are carnelian, chrysoprase, agate, moss-agate, &c. Onyx is engraved as cameos, and small ornaments of various kinds are carved in agate. Rock-crystal was carved by the ancients to form valuable crystal vases and bowls; while at the present day spheres of rock-

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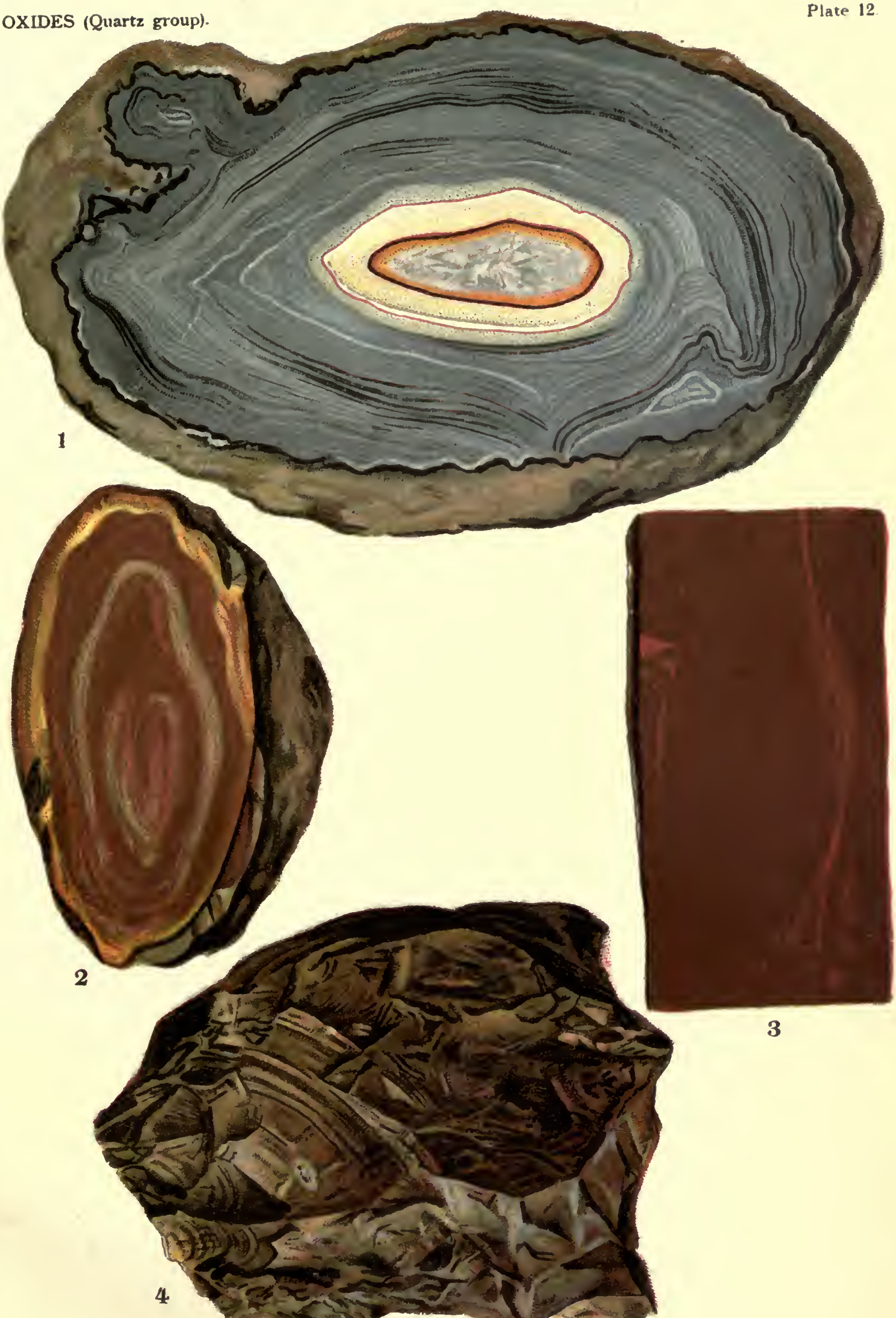
* In this figure the banding in the outer portion is not so clearly defined as may usually be seen in an actual specimen. On the specimens shown in Figs. 1-3, the surfaces have been ground flat, and polished.

OXIDES (Quartz group).

Plate 12.



1, Agate. 2, 3, Jasper. 4, Hornstone.

crystal (or, perhaps, often of glass) find a ready sale to the so-called crystal-gazers. Jasper, being found in larger masses, is used as polished slabs for the decoration of both the inside and the outside of buildings.

Opal (Plate 10, Figs. 4 and 5).—Opal is one of the very few minerals that exhibit no trace of crystalline form. Not even under the microscope can any indication of an internal crystalline structure be detected. The mineral is amorphous, like glass; it is, in fact, merely a solidified jelly, and has been formed by the drying up of masses of gelatinous hydrated silica. A small but variable proportion of water (3 to 10 per cent.) is still retained by the solid. Chemically, opal has the composition of quartz, with the addition of water.

Opal usually occurs as a filling in cavities and fissures in rocks of various kinds, and it is also found in metalliferous veins. Since it usually completely fills the cavity in which it is found (Plate 10, Fig 5), it only rarely has an opportunity of developing any external boundaries of its own; and these, when present, are always rounded (botryoidal or stalactitic) surfaces. The fractured surfaces of the mineral are curved or conchoidal, like those of broken glass (Fig. 5).

In its external appearance opal is very variable; and to gain some idea of its general character the student should inspect a series of specimens in a collection of minerals. It may be perfectly colourless and transparent, as in the variety known as hyalite, or Müller's glass; but more often it is semi-transparent to opaque, and of various colours. Frequently it displays a kind of milky appearance, or opalescence. Further, the character of the lustre may vary from glassy to waxy (wax-opal) or pitchy (pitch-opal). The mineral is not very hard; it can be scratched by quartz, but it will itself scratch glass. The specific gravity (1·9–2·3) is appreciably lower than that of quartz.

Several varieties of opal are distinguished by special names, the more important being common opal (Plate 10, Fig. 4) and precious opal (Fig. 5). The precious opal, with its gorgeous colours flashing and changing with every movement of the stone, is familiar to everybody. These magnificent colours are not, however, inherent in the substance of the opal itself; for if a precious opal be held up between the eye and the window, so that the rays of light pass through the stone, only a pale yellowish or milky colour is to be seen. The play of rainbow colours seen by reflected light is entirely an optical effect, and is due to the interference of the rays of light at the surfaces of fissures or internal films. Such colours are, of course, only to be seen in white light; in the yellow or red light of a photographer's dark room a precious opal will show no play of colours. Certain specimens exhibit a play of colours only when they are immersed in water and the liquid has penetrated into the pores of the stone.

Localities at which common opal is found are very numerous (the specimen represented in Plate 10, Fig. 4, is from Hungary); but precious opal is of much more restricted occurrence. Before the discovery of the rich opal-fields of Australia (New South Wales and Queensland) practically all the precious opal used in jewellery came from Hungary, and it was then much more valuable. In Hungary the mother-rock of the opal is a volcanic rock known as trachyte; in New South Wales it is sandstone, and in Queensland a hard siliceous iron-stone (Fig. 5).

A peculiar variety of opal is the siliceous sinter, or geyserite, which is deposited in a great variety of fantastic forms, and as an encrustation on vegetable matter, from the water of the hot springs of Iceland, the Yellowstone National Park in the United States, and in New Zealand. Somewhat similar in character is the powdery, white material known as diatomite, or infusorial earth (also called tripolite and

Kieselguhr), which consists of the siliceous skeletons of vast numbers of diatoms. These microscopic organisms inhabit both fresh water and salt water, and their remains accumulate on the floor of the ocean and of lakes, forming sometimes thick deposits. This material is largely used for polishing; it is highly absorbent, and when mixed with nitro-glycerine forms the explosive known as dynamite.

Hæmatite (Plate 13, Figs. 1–4).—This important ore of iron is an oxide (the sesquioxide) of iron, Fe_2O_3, known to chemists as ferric oxide. It contains, when pure, 70 per cent of iron. When crystallised it is black or steel-grey, with a brilliant metallic lustre, and is then known as iron-glance, or specular iron-ore; but when massive it is dull red, and is then commonly called red-iron-ore. These two varieties thus differ considerably in their external appearance; but it will be found that when scratched with a knife or crushed they yield a characteristic dark red powder. The resemblance of this colour to that of dried blood is the reason for the name hæmatite, which in Greek means bloodstone.

Crystals of hæmatite belong to the rhombohedral system, but they vary considerably in habit. Usually, however, the crystals are more or less tabular, as in Figs. 1 and 4, and sometimes they have the form of quite thin plates or scales, as in the so-called micaceous iron-ore.

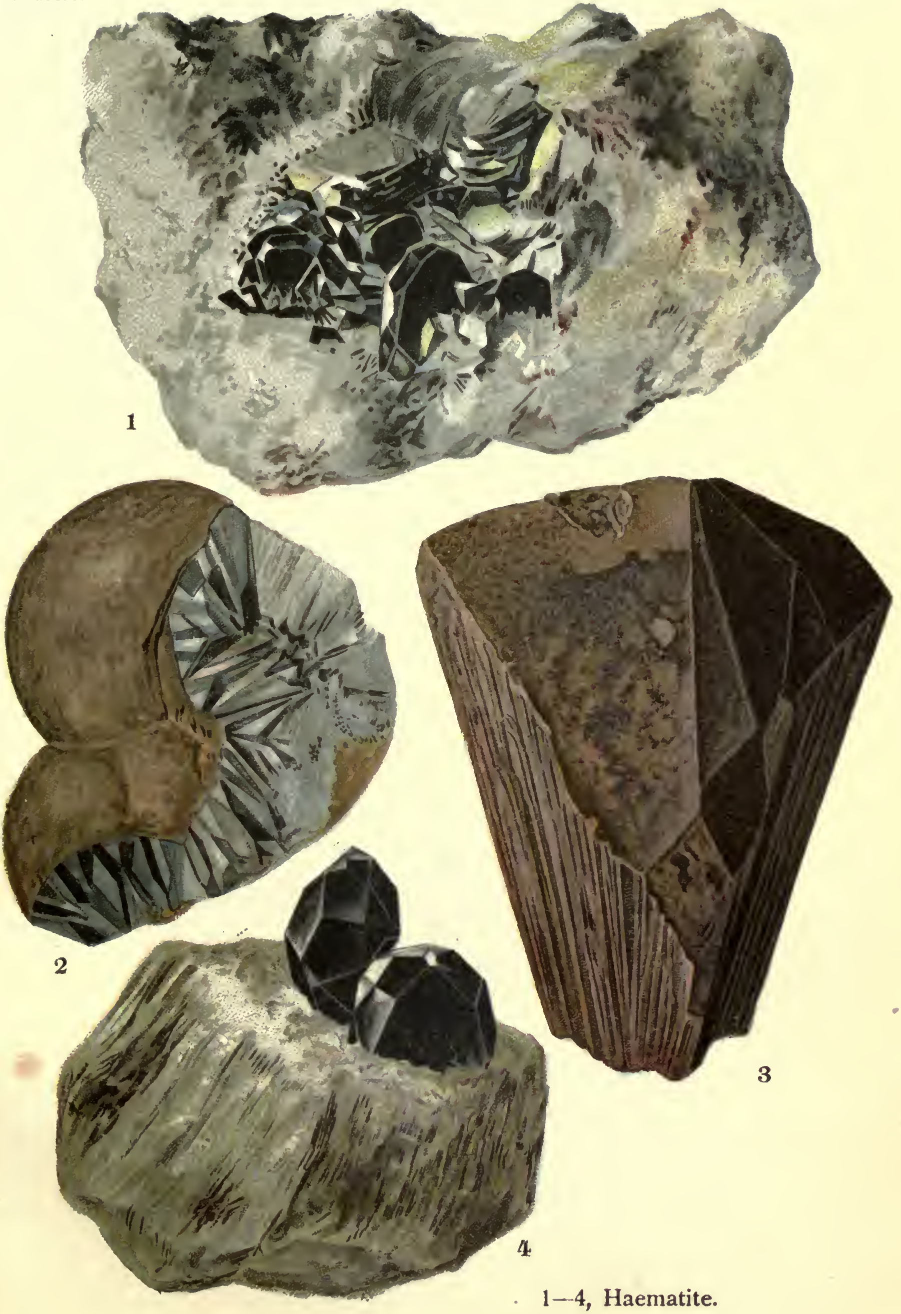
The massive varieties often exhibit an internal radiated structure (Figs. 2 and 3), and when natural external surfaces are present these are rounded or nodular in form—hence the name kidney-iron-ore (Fig. 2). Such masses may be quite soft and earthy, being then of a brighter red colour; or they may be harder and more compact, with a darker colour. The fibrous masses are, indeed, sometimes almost as hard and black as the crystals themselves; and as they can be split up along the fibres into thin rods, such material is known as 'pencil-ore.'

Large deposits of crystallised hæmatite (specular iron-ore) occur in the island of Elba, where they have been extensively worked as an ore ever since the time of the Romans. The specimen shown in Plate 13, Fig. 1, is from these iron-mines. Kidney-iron-ore is raised in large quantities from the several mines in north Lancashire and west Cumberland (Figs. 2 and 3), where the ore fills large cavities in limestone. In these mining districts the red colour of the hæmatite is everywhere in evidence. The crystals represented in Fig. 4 are not from a mining district; they are found singly, and in small numbers, attached to the walls of crevices in mica-schist in the Binn valley in Switzerland. These crystals contain a considerable amount of titanium dioxide, in addition to iron oxide, and they are sometimes regarded as belonging to the closely allied mineral ilmenite. Hæmatite is also found in some volcanic districts (Vesuvius and Madeira) as thin, very brilliant plates, encrusting the surface of the lava.

The chief use of hæmatite is, of course, as an ore of iron. The powdered mineral is also used for polishing (jeweller's rouge), and in the manufacture of paints and red pencils. The hard, compact pencil-ore is cut and polished as pin-stones and ring-stones for use in jewellery; it takes a very brilliant polish, and is of a deep black colour. The same material, when polished, is also used by jewellers and book-binders for burnishing tools.

Magnetite (Plate 14, Fig. 1).—Magnetite, or magnetic iron-ore, is another important ore of iron, which also consists of oxide of iron. Here, however, it is the oxide Fe_3O_4, containing rather more iron (72·4 per cent.), and correspondingly less oxygen, than hæmatite. Chemically, it may be regarded as a combination of ferric oxide (Fe_2O_3) and ferrous oxide (FeO).

In its strongly magnetic character, magnetite is unique



1—4, Haematite.

amongst minerals, no other even approaching it in this respect. Fragments of the mineral are readily attracted by a magnet; and a freely suspended magnetic needle may be turned completely round by holding near to it a piece of the mineral. Further, certain specimens are not only magnetic, but magnetic with polarity; one corner or end of the specimen which attracts one pole of the magnetic needle will repel the other pole; and if the specimen be freely suspended it will, like a magnetic needle, set itself in a north and south position under the influence of the earth's magnetism. Such specimens are the well-known lodestones, or natural magnets.

Crystals of magnetite are not uncommon, but the mineral is more usually found as compact or granular masses. These are dull, black, and heavy, with no very characteristic appearance; but their identity with magnetite may be at once determined simply by holding them near a magnetic needle. The streak, or powder, of the mineral is always black.

The crystals have the form of the regular octahedron, or sometimes of the rhombic-dodecahedron. In the picture (Fig. 1) are shown several lustrous black octahedra on the surface of mica-schist. This specimen is from the Binn valley in Switzerland, where crystals of magnetite are found under exactly the same conditions as crystals of hæmatite (Plate 13, Fig. 4). Excellent crystals of magnetite are also found in the iron-mines at Traversella, in Piedmont, and Nordmark, in Sweden.

As an ore of iron, magnetite is of considerable importance, most of the Swedish ores being of this class, and it is also extensively mined in the Urals and in the state of New York.

Spinel.—Magnetite is a member of the spinel group of minerals, all of which crystallise in the cubic system, usually in octahedral forms; and further, they are analogous in chemical constitution, though not in actual composition. Taking the formula of magnetite, Fe_3O_4 or $FeO.Fe_2O_3$, if we replace the ferrous oxide by magnesium oxide and the ferric oxide by aluminium oxide, we arrive at the formula of spinel, $MgO.Al_2O_3$. Similarly, chromite, or chrome-iron-ore, another member of this group, consists of ferrous oxide with chromic oxide, $FeO.Cr_2O_3$; while an ore of zinc known as gahnite has the analogous formula $ZnO.Al_2O_3$. All these, and several other minerals, belong to the spinel group.

Spinel itself is of interest in being one of the precious stones used in jewellery. It is found in the gem-gravels of Ceylon as small, red, octahedral crystals; and when cut and polished it presents a striking resemblance to the true ruby, being, in fact, known as 'spinel-ruby,' or 'balas-ruby.' It may, however, be readily distinguished from the true ruby by its optical characters, specific gravity, and hardness.

Corundum (Plate 14, Fig. 2).—The oxide of the light and useful metal aluminium is known to the chemist as alumina (Al_2O_3), to the mineralogist as corundum, to the jeweller as ruby and sapphire, and to the lapidary as emery. All these substances, or rather varieties, of the mineral corundum, though differing so widely in their external and general appearance, are identical in their essential characters—that is, chemical composition, crystalline structure, hardness, specific gravity, and other physical and optical characters. The differences they exhibit depend solely in the presence of smaller or greater amounts of admixed colouring matter or impurities. A convincing proof of this is that the same stone, even when faceted as a gem, may sometimes show bands of different colours.

When quite pure, crystallised corundum is perfectly colourless and transparent. But when small amounts of various inorganic colouring materials are present the crystals may be brilliantly coloured, or, we may say, dyed, and yet retain their transparency. The colours of such transparent stones of gem-quality, or precious corundum, may be red, orange, yellow, green, blue, or violet—all the colours of the rainbow. These differently coloured stones are unfortunately designated by special names in jewellery, much to the confusion of the uninitiated. It would, indeed, be just as reasonable to call silk ribbon by different names according to the colour it has been dyed.

When the crystals are cloudy, or opaque, due to the presence of fissures and the enclosure of foreign materials, the mineral is known as common corundum, as distinct from precious corundum. When it is granular and mixed with a considerable amount of foreign matter, especially magnetite, we have the variety known as emery.

These two more abundant forms of corundum are of considerable importance for abrasive purposes, being used for the making of corundum-wheels and emery-cloth, or as powder for grinding precious stones and in lapidaries' work generally. This application of corundum depends, of course, on its great hardness (No. 9 on the scale). With the exception of diamond, corundum is the hardest of all minerals. Recently, however, its place as an abrasive agent has been taken by the still harder artificial product carborundum, a silicide of carbon.

Crystals of corundum belong to the rhombohedral system. The crystal represented on the matrix of crystalline limestone in Plate 14, Fig. 2, consists of a hexagonal prism truncated at right angles by the base, and with small triangular faces of a rhombohedron on three of its corners. A more usual form for crystals of sapphire is, however, a steeply inclined six-sided pyramid.

The specific gravity (4·0) of corundum is considerably greater than that of metallic aluminium (2·5), and, with the exception of zircon and some varieties of garnet, it is the heaviest of the precious stones. Why the combination of the light metal aluminium with the gas oxygen should produce a stone of such density is difficult to understand.

An interesting optical effect is exhibited by the varieties known as 'star-sapphire' and 'star-ruby.' When cut and polished with a convex surface, these show a six-rayed star of reflected light, which travels over the surface as the stone is moved about, just as does the single band in the cat's-eye mentioned on p. 90.

Corundum occurs embedded in granite, gneiss, serpentine, or crystalline limestone. It is not a widely distributed mineral, though abundant at certain localities. It is mined on a large scale for abrasive purposes in Ontario and North Carolina; and there have long been important emery-mines in Asia Minor and the island of Naxos. Rubies of the best quality are those found in a crystalline limestone, or marble, at Mogok, in Upper Burmah. The best sapphires are from the gem-gravels of Ceylon, and stones of good gem-quality are also found in Australia and the United States.

Of special interest are the variously coloured corundums of gem-quality, which within the last few years have been made artificially in large quantities by a cheap and simple process. These stones possess all the characters of natural crystallised corundum, differing from it only in their mode of origin, and when cut and polished they furnish handsome gems.

Cassiterite (Plate 14, Fig. 3).—Cassiterite, or tin-stone, is practically the only ore of tin, other minerals containing this metal being of quite rare occurrence. It is the dioxide, SnO_2, and contains 78·6 per cent. of metallic tin.

It is a very heavy mineral (sp. gr. 7), usually of a dark-brown colour, though this may vary from almost white to black. Most frequently it is met with as compact masses, or as grains disseminated through the rock, but crystals are not

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uncommon. Sometimes it has a fibrous structure resembling that of wood, being then known as 'wood-tin.'

The crystals are tetragonal, and are, as a rule, rather small. Their form is that of a square prism terminated by a square pyramid. These forms are, however, not always easily made out, and in the picture (Fig. 3) they are not very obvious. Here, however, a still more characteristic feature of crystals of cassiterite is represented; in the lower left-hand corner of the picture are seen two twinned crystals, with their very characteristic re-entrant angles. The faces of the crystals are very brilliant, with a lustre like that of diamond.

As above mentioned, the most characteristic feature of the mineral is its heaviness, but the only certain way of determining a specimen devoid of crystals is to test for the presence of tin. This may be readily done by heating the powdered mineral, mixed with sodium carbonate, on charcoal in the reducing flame of the blowpipe, when bright beads of metallic tin are obtained.

Cassiterite is not a mineral of wide distribution, but in certain districts it is met with in considerable abundance. Veins of tin-ore usually occur in the immediate neighbourhood of granite, as in the long-known tin-mining district of Cornwall. With the weathering and breaking-down of the tin-bearing rocks, the heavy, indestructible tin-stone collects in the beds of rivers, and is then known as stream-tin. Alluvial deposits of stream-tin are largely worked in the Malay Peninsula and in Australia. Another district which was formerly of considerable importance is in the mountains between Saxony and Bohemia; the specimen represented in Plate 14 is from Schlaggenwald, Bohemia.

Zircon (Plate 14, Fig. 4).—This mineral is a double oxide of zirconium and silicon, with the formula $ZrO_2.SiO_2$. Writing this formula in the form $ZrSiO_4$, the composition is represented as a silicate of zirconium. Owing, however, to the remarkable similarity of the crystalline form of zircon to that of cassiterite, it seems more natural to class this mineral with the oxides rather than with the silicates.

Zircon is found only as crystals, though these may sometimes be much rounded and water-worn, especially when found in gem-gravels. The crystals are tetragonal, consisting of a square prism capped by a square pyramid. In the picture (Fig. 4) we see two such crystals partly embedded in felspar from the Ilmen Mountains, in the southern Urals; one crystal, seen in side view, shows the edge of the large square prism truncated by narrow planes (only one is visible in the picture) of a second square prism; the other crystal, seen in end view, shows only the four faces of the square pyramid.

The colour of zircon is somewhat variable; brown, as shown in the picture, is the most frequent colour of the crystals. Reddish-brown stones of gem-quality are known as hyacinth, and green and yellow stones are sometimes called jargoon. Owing to these bright colours and to its high degree of brilliancy and hardness, zircon, when cut and polished, makes a very effective gem-stone; and when colourless it may even be mistaken for diamond. Stones of a reddish-brown colour may be completely decolorised by heat, and are sometimes sold as diamonds.

A very remarkable feature presented by zircon is the wide range of its specific gravity, which in different specimens may vary from 4·0 to 4·7. Further, certain stones when heated change, not only in colour, but also in specific gravity.

Zircon is an almost invariable constituent of granite and certain other rocks of igneous origin; but, as a rule, the crystals are extremely minute, and present in only relatively small amount. When such rocks are broken down by weathering, the zircon, being indestructible, is carried away by running water with the debris. For this reason microscopic crystals of zircon may be detected in almost all sands, gravels, and sandstones. The larger pebbles and water-worn crystals of zircon so abundant in the gem-gravels of Ceylon have in the same way been derived from the granitic rocks of the island.

Pitchblende (Plate 14, Fig. 5).—Pitchblende is an ugly black mineral, which in colour, lustre, and fracture bears some resemblance to pitch. When, however, a specimen is handled, it will at once be noticed that it is far heavier than pitch—far heavier, indeed, than most other materials. Its specific gravity ranges from 8·0 to 9·7, the former value being greater than the specific gravity of iron, and the latter greater than that of copper.

In spite of its unattractive appearance, pitchblende has within recent years come to be a mineral of extraordinary interest by reason of its remarkable radio-active properties. The invisible rays continually being emitted by a specimen of pitchblende are capable of acting on a photographic plate; so that it is possible with its aid to photograph the outlines of objects in the dark. The rays may also cause certain substances (especially artificially prepared hexagonal zinc sulphide) to become luminous, or to phosphoresce, in the dark. Again, they possess the power of making the air a conductor of electricity; so that if a piece of pitchblende be placed near a charged gold-leaf electroscope, the charge of electricity rapidly escapes, and the gold-leaves fall together.

These remarkable properties were first discovered in uranium compounds by the late Professor Henri Becquerel in 1896; and the observation that they are strongly marked in pitchblende led Madame Curie to the isolation of the particular elements—radium and polonium—to which these special effects are due. The amount of radium contained in pitchblende—the richest ore of radium—is, however, extremely minute, not more than one part in five million. Several tons of the mineral have to be treated by a long series of complex chemical operations to obtain even a very small amount of a radium compound.

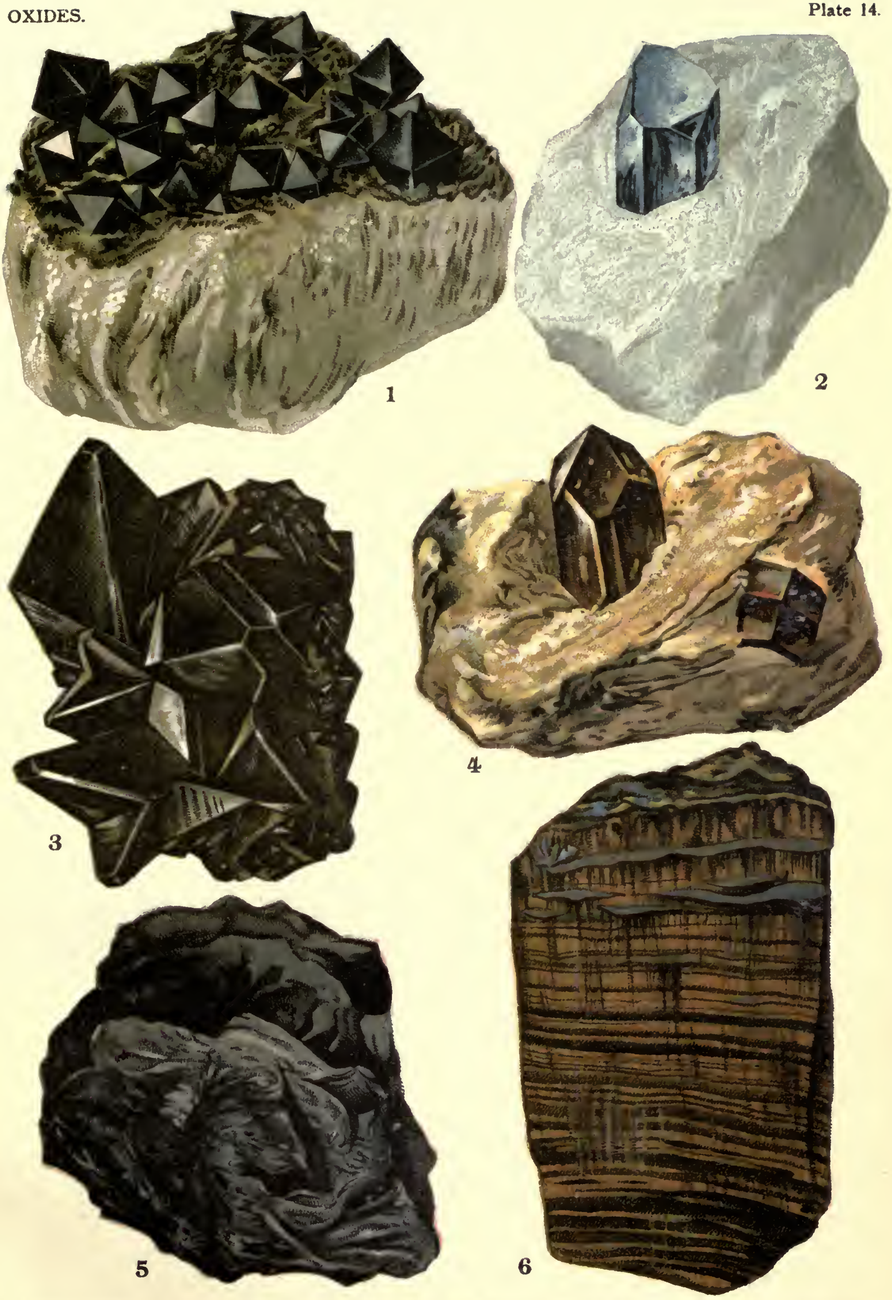
Chemically, pitchblende is an oxide of uranium, and on this account it is known to mineralogists as uraninite. Oxides of some other rare metals are often also present in variable amount.

The most productive mines of pitchblende are those at Joachimsthal, in Bohemia, where it occurs in metalliferous veins, together with ores of silver and cobalt. It is also found in some of the Cornish mines. At these places it is always massive; but in the felspar quarries in the south of Norway it is found as small cubic crystals (known by the special names bröggerite and cleveite) embedded in the felspar.

Limonite (Plate 14, Fig. 6).—On account of its usual rusty-brown colour this important ore of iron is often known as brown-iron-ore. Certain masses when presenting a rounded (nodular or stalactitic) surface may, however, be black and shining; but when such masses are broken open, or scratched with a knife, the characteristic brown colour is at once rendered evident. These more compact masses usually exhibit an internal fibrous structure, with a banded arrangement perpendicular to the fibres (Fig. 6). Crystals of limonite are quite unknown. Earthy or powdery masses are the most frequent.

Limonite is a hydrated oxide of iron, with the chemical formula $2Fe_2O_3.3H_2O$—that is, the same as hæmatite, with the addition of water. It is the final product of weathering of all iron-bearing minerals.

As a yellow, powdery, or slimy substance, it is deposited by the waters of chalybeate springs; and material of a similar nature is formed in marshes and on the beds of certain lakes. The latter constitutes the Swedish lake-ore, or bog-



1, Magnetite. 2, Corundum. 3, Cassiterite. 4, Zircon. 5, Pitchblende. 6, Limonite.

iron-ore; and when it has been all collected from a particular spot a fresh deposit is ready for working after the lapse of a number of years. Limonite is the most important iron-ore in Germany, and large quantities are also mined in the north of Spain. Besides being used as an ore of iron, the purer, powdery variety, or yellow-ochre, is used as a pigment.

Manganese Oxides (Plate 15).—The three species manganite, pyrolusite, and psilomelane, represented on Plate 15, may conveniently be treated together, for they closely resemble one another in appearance, and are, as a rule, not readily to be distinguished; further, they occur together, and are all mined and put to the same uses.

In colour they are all black, usually with a semi-metallic lustre; their streak, or powder, is also black, and some varieties are so soft that they soil the fingers when touched. The black streak is, indeed, the most characteristic and constant feature of these minerals; if we have a soft, black mineral which gives a black streak we may be pretty certain that it is one of these oxides of manganese.

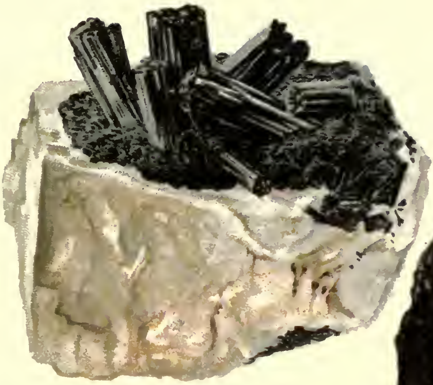
The only species which occurs distinctly crystallised is *manganite* (Fig. 1). The crystals are usually prismatic in form, and at a few localities very fine specimens are to be found, but elsewhere they are rare. The picture shows bundles of prismatic crystals on barytes, and represents a specimen from Ilfeld, in the Harz Mountains, Germany. This species is the hydrated oxide, $Mn_2O_3.H_2O$.

Another species, *pyrolusite* (Figs. 2 and 3), is perhaps the most abundant of these oxides of manganese. It usually forms radiating aggregates of platy or needle-like crystals, as represented in the pictures. In chemical composition it approximates to the dioxide, MnO_2.

A third species, *psilomelane* (Fig. 4), is never found crystallised, but usually as nodular or stalactitic masses with rounded surfaces. The stalactites have sometimes an internal radiated structure, as shown in the picture (where they have been broken across; three of the natural rounded ends are also shown). The surface of these masses is often very smooth and shining, and the material is then quite hard. In the variety known as wad the material is, however, quite soft, and sometimes so porous that it floats on water. Psilomelane and wad are very variable in chemical composition; though consisting largely of manganese dioxide, they also contain oxides of barium, potassium, cobalt, &c.

These black manganese minerals owe their origin to the alteration by weathering of other minerals containing manganese, and in some places they form large deposits. Such deposits are mined principally in Brazil, Russia, and India. These minerals have long been used for the manufacture of chlorine and bleaching powder and for decolorising glass. More recently, large quantities have been used for preparing the spiegeleisen and ferro-manganese employed in the manufacture of iron.

Cuprite.—The only remaining oxide which need be mentioned in this place is the suboxide of copper (or cuprous oxide) Cu_2O. It is sometimes found beautifully crystallised in cubes or octahedra, and the crystals, being very brilliant, transparent, and of a rich ruby-red colour, are very attractive in appearance. On this account the mineral is also known as ruby-copper, or red-copper-ore. In a peculiar variety known as chalcotrichite (or hair-copper), the cubes are enormously elongated in the direction of one of their edges, so resembling fine hairs; and when, as is usually the case, large numbers of these hair-like crystals are closely aggregated or matted together, the material has the appearance of crimson plush. Another variety is earthy in character and intermixed with limonite, and from its appearance it is known as tile-ore. In some copper-mining districts cuprite is of importance as an ore.



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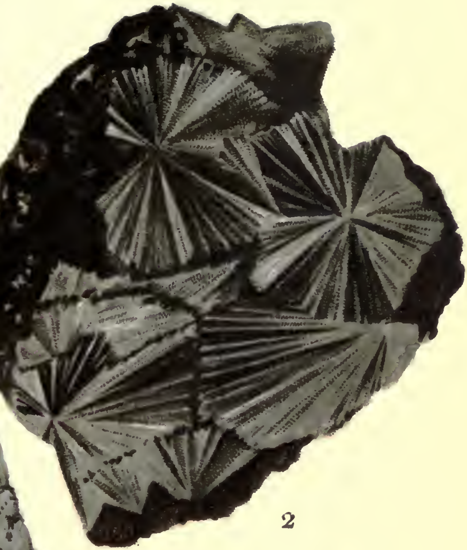

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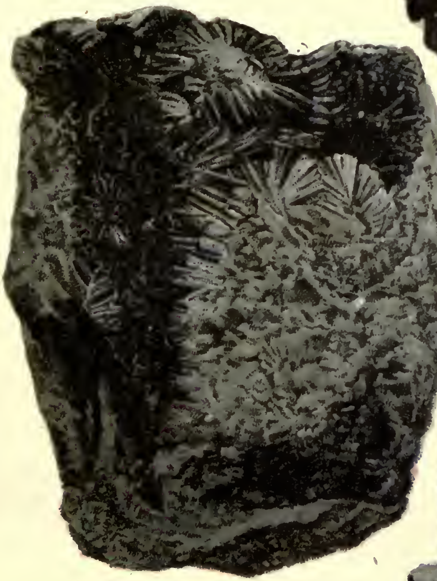

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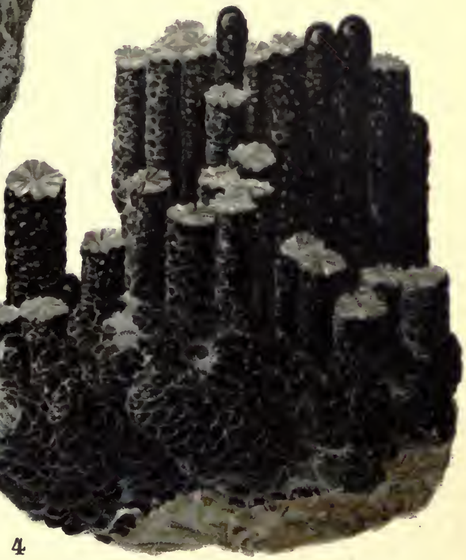

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1, Manganite. 2, 3, Pyrolusite. 4, Psilomelane.

CHAPTER IX.

The Carbonates.

From the oxides considered in the last chapter, we pass to the very large series of oxygen-salts, and the first group of this series is that of the carbonates. These consist of carbon and oxygen in combination with one or other of the metals; that is, they are salts of carbonic acid (H_2CO_3), which acid in its gaseous form is the well-known carbon dioxide (CO_2), produced when all organic substances are burnt in the air. In addition to these elements, some minerals of this group may contain the elements of water, being hydrated carbonates; while others may contain an excess of the metal in the form of hydroxide, these being hydrated basic carbonates.

When a carbonate is heated to redness, the carbon dioxide it contains is expelled, leaving the metallic oxide; this takes place when limestone ($CaCO_3$) is burnt to give quicklime (CaO). Or the carbon dioxide may be expelled simply by placing the carbonate in acid, when the gas that is liberated bubbles through the liquid. This property that carbonates have of effervescing in contact with acid affords a simple test by which they can always readily be detected. It is only necessary to place a drop of acid (dilute hydrochloric acid is the best) on a mineral to decide whether or not it is a carbonate. In certain cases, however, it may be necessary to place the powdered mineral in warm acid before the effervescence is produced.

Most carbonates, when in a pure state, are colourless and transparent. They are all fairly soft, and can be scratched with a knife. As mentioned below (pp. 111, 116), most of these minerals fall into well-defined isomorphous groups.

Calcite (Plate 16, Figs. 1–3).—Next to quartz, calcite or calc-spar is the most abundant of minerals, and it also appears in a great variety of forms or guises. The common and plentiful rocks of the limestone class (chalk, oolite, marble) consist entirely, or almost entirely, of compact calcite. These rocks have in most cases been formed by the accumulation of the calcareous remains of various marine organisms, such as foraminifera, corals, molluscs, &c., which, like calcite itself, are composed chemically of calcium carbonate ($CaCO_3$).

Calcite is remarkable for the frequency with which it is found in a well-crystallised condition; indeed, calcite crystals are the commonest of all kinds of crystals. Further, they display a greater variety of forms than is met with in any other mineral. We may have plate-like crystals, which are sometimes as thin as a sheet of paper; or the crystals may be prismatic in habit, with either a hexagonal or a triangular cross-section, and they may sometimes be long and as slender as needles. Or, again, we may have rhombohedra, either flat or steep, or various scalenohedral forms. Calcite of the several forms just enumerated is often known by several trivial names, such as paper-spar, cannon-spar, rhomb-spar, nail-head-spar, and dog-tooth-spar. Combinations of these simple forms give rise to an almost endless variety of forms for crystals of calcite. In Plate 16, Fig. 3, the form of the crystals is that of the primitive rhombohedron; in Fig. 2, it is another more acute rhombohedron; and in Fig. 1, a combination of a hexagonal prism, a scalenohedron, and an obtuse or flat rhombohedron. Although differing so widely in form and appearance, all these crystals belong to one common type. They are each symmetrical with respect to three planes of symmetry, with a three-fold arrangement about the vertical axis; and the angles between similar faces are always the same.

A very important property of crystals of calcite is that of splitting, or cleaving, with great ease in three directions parallel to the faces of the primitive rhombohedron. Any crystal of calcite, whatever be its external form, may be broken up by a hammer into a number of small rhombohedra, with smooth and bright faces. This cleavage rhombohedron is of the same form as the primitive rhombohedron (Fig. 3), with identical angles (105° 5′, or 74° 55′) between adjacent faces. The plane angles on the rhomb-shaped faces are 102° and 78°.

This perfect cleavage of calcite is of the first importance as an aid to the recognition of the mineral. Other characters of importance in this direction are the low hardness (No. 3 on the scale) and low specific gravity (2·72); the mineral can be readily scratched with a knife. Another test that may be readily applied is given by the fact that the mineral effervesces freely with cold, dilute acid. A minute fragment of calcite, when placed in a drop of hydrochloric acid on a microscope slide, quickly dissolves with effervescence; on adding a drop of sulphuric acid to this solution, and allowing the liquid to evaporate, star-like groups of crystals of gypsum are formed, and these present a very characteristic appearance under the microscope.

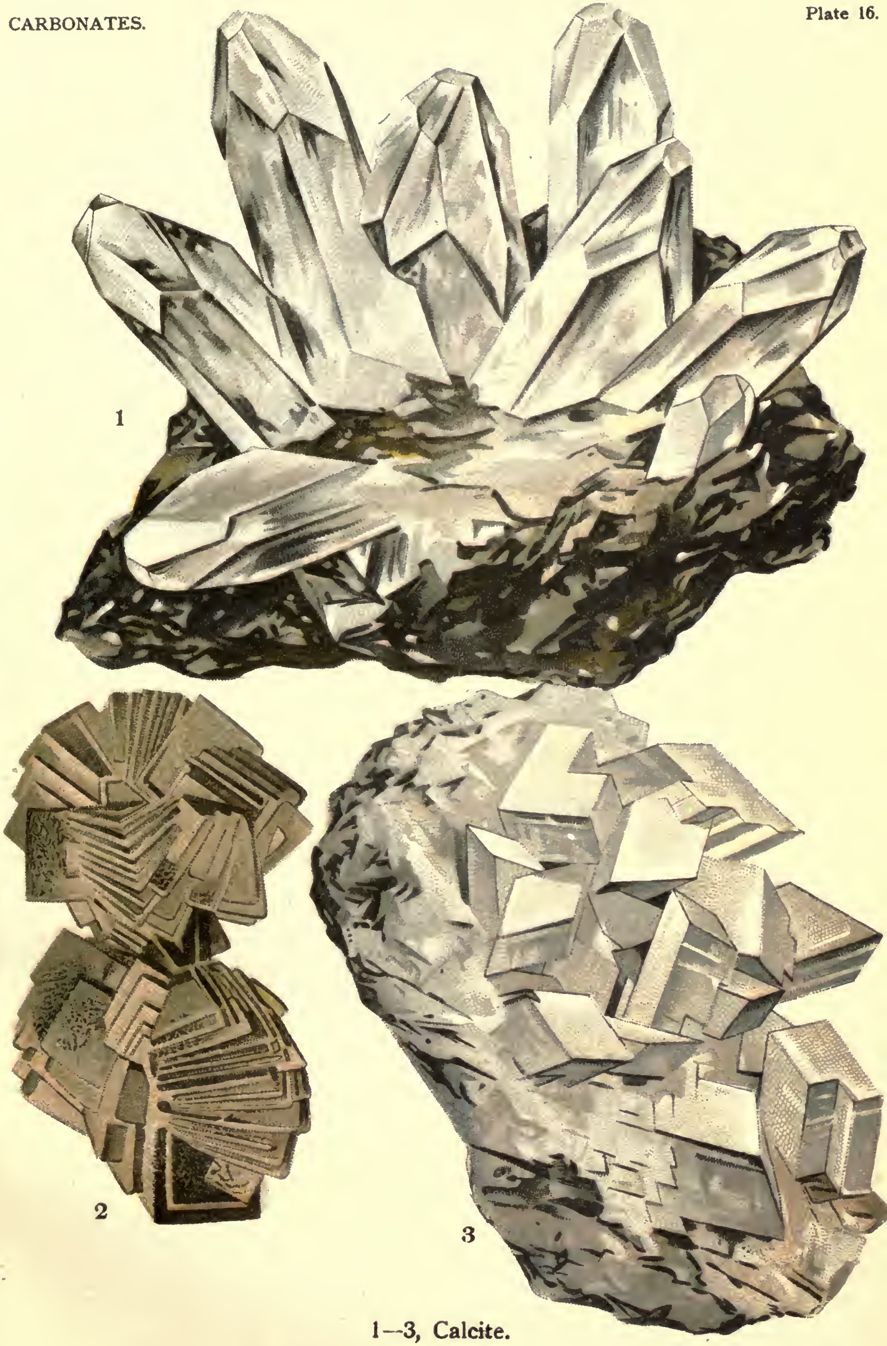
Crystals of calcite vary not only in their geometrical form, but they may also vary considerably in their degree of transparency and colour. Most frequently they are of a pale yellowish or reddish colour, owing to the enclosure of hydrated oxides of iron, and are only semi-transparent. When the material is quite pure it is perfectly colourless and transparent. The purest crystallised material of the best quality comes from one spot in Iceland, and is known as Iceland-spar. This is much used for making optical prisms for polarising apparatus.

The use just mentioned depends on a very peculiar property possessed by crystals of calcite—namely, that of double refraction, a property which is possessed by many other minerals, though rarely to such a high degree. If a cleavage-rhomb of Iceland-spar be placed over an object (such as a dot or a cross drawn on a sheet of paper), the object will be shown double through the spar, there being seen two dots or two crosses. A ray of light on entering a crystal of calcite is split into two rays, which travel along different paths through the crystal. For this reason Iceland-spar is also known as doubly-refracting spar.

Beautiful crystallised specimens of calcite are to be found at very many places. One of the best-known localities is in the west Cumberland iron-mining district in the neighbourhood of Egremont. Here large fissures or cavities in the hæmatite iron-ore and in the adjacent limestone are completely lined with numberless sparkling crystals, which are often quite transparent and tipped with delicate shades of red. Enormous crystals of water-clear calcite have been found in cavities in lava in Iceland; and magnificent crystals of a rich wine-yellow or wine-red colour are met with in the lead and zinc mines near Joplin, in Missouri. Many other well-known localities might easily be mentioned. The specimen represented in Plate 16, Fig. 1, is from Egremont, in Cumberland, the crystals here shown being on a matrix of iron-ore. The specimen in Fig. 2 is from Fontainebleau, in France; the closely aggregated groups of rhombohedral crystals from this locality are remarkable in enclosing a large amount of sand.

The well-known stalactites, found hanging from the roofs of limestone caves, consist of calcite. These have been formed by the deposition of calcium carbonate from the water which drips from the roof of the caves.

Calcite may be taken as the type of a group of minerals known as the rhombohedral carbonates. These all crystallise in rhombohedra, which differ only slightly from the primitive



1—3, Calcite.

rhombohedron of calcite, there being a difference of only a few degrees in the angles between the faces. They also all possess the same perfect cleavages parallel to the faces of this rhombohedron. The several members of the group, though consisting of carbonates of different metals, are yet analogous in their chemical constitution, for the metals they contain are closely related. They have the general formula $R''CO_3$, where R'' may stand for calcium, magnesium, iron, zinc, or manganese. We have here an excellent example of an isomorphous group of minerals.

Three of the minerals of this group, which are represented in Plate 17, Figs. 1–3, will each be specially described below. Others, which we may mention by name in this place, are magnesite, or magnesium carbonate ($MgCO_3$), and dolomite ($CaCO_3.MgCO_3$), in which both calcium and magnesium are present, this species being midway between calcite and magnesite.

Calamine (Plate 17, Fig. 1).—This is the carbonate of zinc ($ZnCO_3$) belonging to the group of rhombohedral carbonates. Distinctly developed rhombohedral crystals are, however, quite rare, and are always small. More usually the mineral forms masses with concentric shelly layers and a nodular surface, or it is frequently earthy or compact. In colour it is often creamy or yellowish, though sometimes bluish or greenish (Fig. 1). It is a mineral presenting no very distinctive external features, and it is frequently mistaken for other minerals. The only safe way of determining it is to test for the presence of carbonate and of zinc, the latter by the method already mentioned under zinc-blende (p. 66).

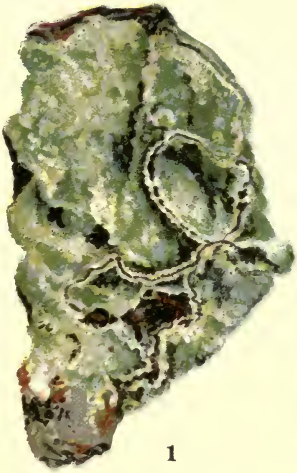
Calamine occurs in metalliferous veins, together with zinc-blende, and it frequently forms extensive bedded deposits in limestones. It contains 64·8 per cent. of zinc, and is an important ore of this metal.

Chalybite (Plate 17, Fig. 2).—The rhombohedral carbonate of iron ($FeCO_3$), known as chalybite or spathic iron-ore, or sometimes as siderite, is often found as small, well-developed crystals of various forms, the rhombohedron being the most frequent. Brown crystals of this kind are shown, in association with galena, in Plate 5, Figs. 3 and 4; and a brown encrustation of chalybite, on fluor-spar, is shown in Plate 9, Fig. 1. More often the mineral occurs as granular masses showing numerous bright cleavages on the fractured surfaces; sometimes such masses may be very coarsely crystalline, with large cleavage surfaces. Frequently the material is compact, with a more or less pronounced radiated structure (Plate 17, Fig. 2). It is then often mixed with various impurities, such as clay and carbonaceous matter, as in the varieties known as clay-iron-stone and black-band iron-stone, which are of great importance as ores of iron.

The crystallised varieties of chalybite are more usually found in metalliferous veins—for instance, in Cornwall and in the Harz Mountains; while the granular and compact varieties form beds in sedimentary rocks. In the coal-measures of England and South Wales we have the abundantly occurring clay-iron-stone and black-band iron-stone. The important iron-ores of the Cleveland district of Yorkshire consist of oolitic chalybite, forming beds in the Lias formation. When chemically pure, chalybite contains 48·2 per cent. of iron, but usually, owing to the presence of admixed impurities, the ore does not contain so high a percentage as this.

Rhodochrosite (Plate 17, Fig. 3).—The carbonate of manganese ($MnCO_3$) known as rhodochrosite, or manganese-spar, is very different in its appearance from the manganese minerals which we have previously considered (p. 105). Instead of being black and dirty, it is of a beautiful rose-red colour, and it is found as clean-looking rhombohedral crystals (Fig. 3). These crystals possess the perfect rhombohedral

CARBONATES.



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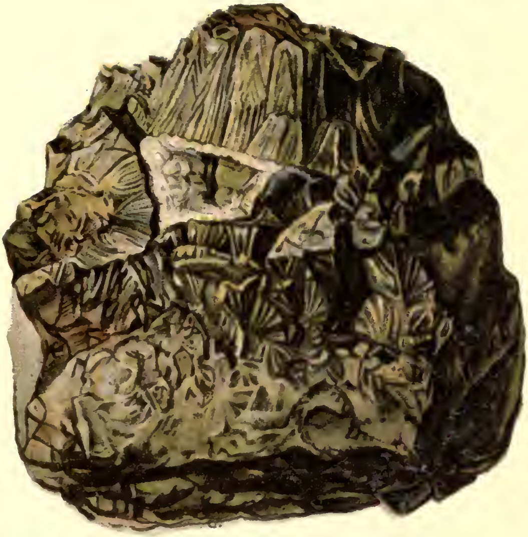

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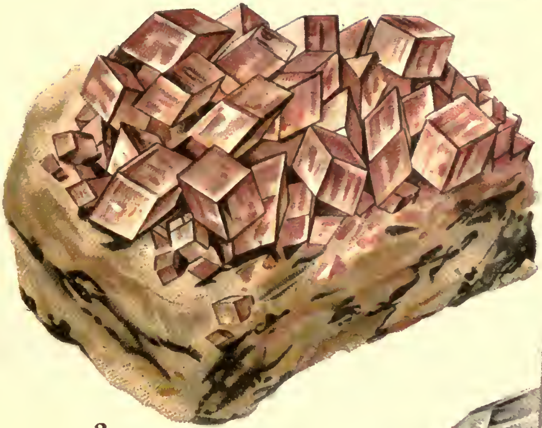

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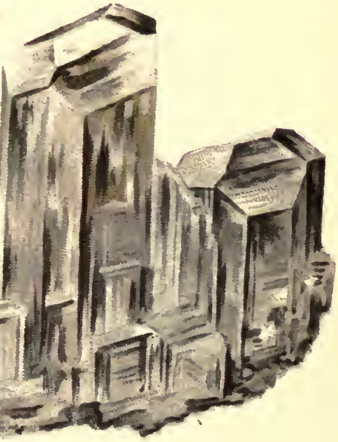

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1, Calamine. 2, Chalybite. 3, Rhodochrosite. 4, Cerussite.

cleavage characteristic of this group of carbonates, and consequently they sometimes exhibit a more or less marked pearly appearance on their surfaces. More frequently, however, the faces of crystals are curved, sometimes so pronouncedly that the crystals somewhat resemble a saddle in form. The mineral also occurs as granular masses, with a globular surface, being then sometimes known as raspberry-spar, as suggested by its appearance.

Crystallised rhodochrosite is found in cavities in limonite at Horhausen, in Rhenish Prussia, and in metalliferous veins at Kapnik, in Hungary. The best crystals are found with iron-pyrites at various places in Colorado (Fig. 3). The massive mineral forms extensive beds in limestone in the Pyrenees, where it is mined as an ore of manganese. This ore cannot, however, be used for the same purposes (bleaching, &c.) as the black ores of manganese, since it contains no dioxide; it is used only in the manufacture of iron.

Aragonite (Plate 18, Figs. 1–3).—In chemical composition aragonite is the same as calcite, being calcium carbonate ($CaCO_3$). Nevertheless, we have here two quite distinct minerals, which differ not only in their crystalline form, but also in all their physical characters. We have, in fact, the same chemical compound crystallising in two totally distinct modifications, just as carbon crystallises either as diamond or as graphite (see p. 49), and as sulphur forms either orthorhombic or monoclinic crystals (p. 52). In other words, calcite and aragonite are dimorphous forms of calcium carbonate.

In its general appearance aragonite is, however, not unlike calcite, the material being usually colourless, white, or pale-coloured, either transparent or translucent, and with a glassy lustre. And, indeed, when the material is very minutely crystallised it is not always quite easy to distinguish between calcite and aragonite.

Distinctly formed crystals of aragonite are comparatively rare; their system of crystallisation is orthorhombic, and they are usually prismatic in their development. The orthorhombic form is, however, very often obscured by twinning, and frequently three crystals are twinned together to produce a form closely resembling a hexagonal prism, as shown in Plate 18, Fig. 3. Twinned crystals of this kind are found in Aragon, Spain—hence the name aragonite for this species; in the sulphur-mines near Girgenti, in Sicily; at Herrengrund, in Hungary (Fig. 3); and in the copper-mines at Corocoro, in Bolivia, where the crystals are often replaced by native copper, with their original form still preserved.

More frequently, crystals of aragonite have the form of very steep spires, spikes, or fine needles, which are usually aggregated in divergent groups or in delicate feathery forms. This acicular, or needle-like, habit of the crystals is very characteristic of aragonite; but it is not correct to suppose (as is frequently done) that all needle-like crystals of calcium carbonate are aragonite, for we may also have acicular crystals of calcite.

We have already seen that when a crystal of calcite is broken, the surfaces of fracture are quite plane and smooth, since the mineral possesses perfect cleavages parallel to the faces of the primary rhombohedron. In aragonite, on the other hand, there is no cleavage, and the fractured surfaces of the crystals are curved (or sub-conchoidal), with a glassy or almost resinous appearance. This presence or absence of cleavage is of prime importance, and affords a very ready means of distinguishing between crystals of calcite and aragonite. If we take a thin, prismatic or needle-shaped crystal (which, having been previously tested with acid, we know to be calcium carbonate) and snip off the end, we can at once say whether the mineral is calcite or aragonite; if it be calcite, it will break along a smooth surface, set obliquely to the length of the prism; while if it be aragonite, there is no plane surface of fracture.

Most frequently, however, aragonite is met with in a very minutely crystallised condition, forming finely fibrous compact masses of various shapes with rounded outlines. These rounded shapes may be nodular or coralloidal, and they are often of considerable complexity and beauty. A coralloidal (i.e. coral-like) form is represented in Fig. 1, this being the so-called *flos-ferri* (i.e. flower of iron), which is found in the iron-mines at Eisenerz, in Styria. These snow-white, branching forms are often extremely beautiful, and they present quite the appearance of certain organic structures. When one of these branches is broken across it will be seen to have an internal radiated structure, due to the very close aggregation of numberless fine, needle-like crystals, arranged perpendicular to the axis of the branch.

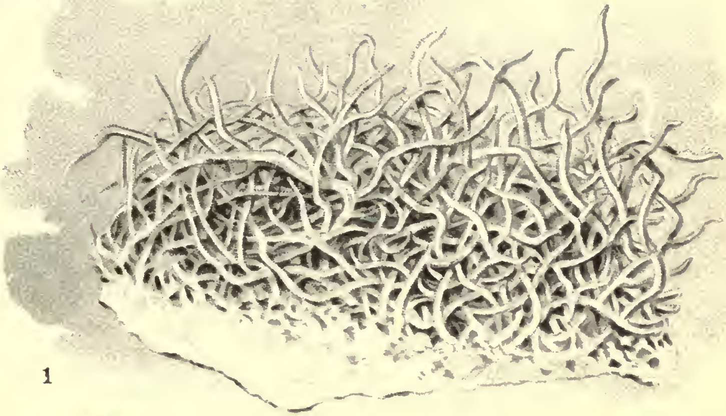
Another well-known form of aragonite is the so-called *pisolite*, or pea-stone, represented in Fig. 2, which consists of concentric shells of material, forming small balls about the size of peas; numbers of these balls are closely packed together, and the spaces between them filled with material of the same kind, to form large, compact masses. The several layers of the balls can be readily peeled off like the coats of an onion; and each layer when broken across shows a finely fibrous structure, with the fibres arranged perpendicular to the surfaces of the shells. Pisolitic aragonite is being deposited at the present day by the hot springs at Carlsbad, in Bohemia, the waters of which carry calcium carbonate in solution. Many other waters, especially in limestone districts, contain calcium carbonate in solution; but at the ordinary temperature this is deposited as calcite and not as aragonite. The specimen represented in Fig. 2 is from Carlsbad.

The finely fibrous forms of aragonite just described are much more frequent than distinctly formed crystals; in calcite, on the other hand, crystals are of more common occurrence. We must not, however, assume that all fibrous forms of calcium carbonate are aragonite, for they are also met with in calcite. Indeed, most stalagmitic or onyx marbles consist of calcite, and not of aragonite, as often stated.

Aragonite is both rather harder (hardness $= 3\frac{1}{2}$–4) and denser (sp. gr. 2·93) than calcite; but in finely fibrous and perhaps somewhat cellular masses these differences may not be appreciable. A doubtful specimen may, however, often be determined by floating a minute fragment in a heavy liquid together with known fragments of calcite and aragonite. The differences in the optical characters of the two minerals are also of assistance for purposes of determination.

Both calcite and aragonite effervesce freely in cold, dilute hydrochloric acid; but although these two minerals are identical in chemical composition, it does not follow that they will always show the same chemical reactions, for they possess differences in their molecular structure. For instance, if the finely powdered material be added to a dilute solution of cobalt nitrate and this be boiled for a few minutes, aragonite becomes lilac-red in colour, whilst calcite remains white.

Cerussite (Plate 17, Fig. 4; Plate 18, Fig. 4).—Cerussite, or white-lead-ore, is carbonate of lead ($PbCO_3$), crystallising in the orthorhombic system. The crystals are closely related in form, angles, and twinning to crystals of aragonite, so that these two minerals, together with some others (namely, witherite, or barium carbonate, and strontianite, or strontium carbonate), belong to the same isomorphous group. Of this group of orthorhombic carbonates, aragonite may be taken as the type, just as calcite was taken as the type of the isomorphous group of rhombohedral carbonates (p. 111). Now we have already seen that calcite and aragonite are



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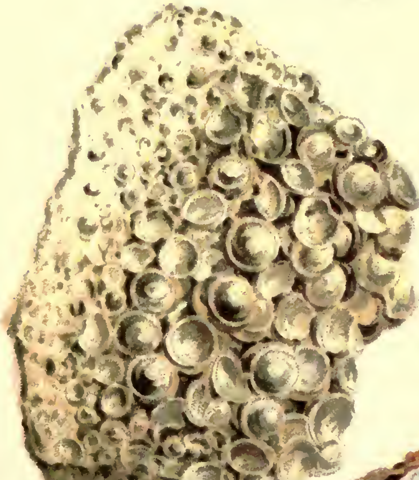

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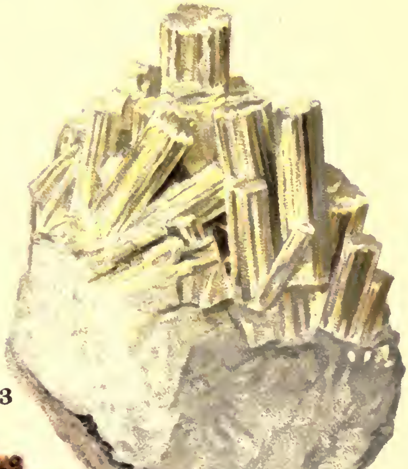

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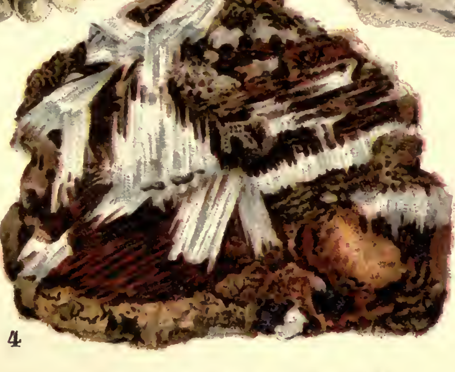

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1—3, Aragonite. 4, Cerussite.

dimorphous (p. 113), so we have here an excellent example of two parallel groups of isomorphous minerals, forming all together what is known as an isodimorphous series.

Simple crystals of cerussite, such as represented in Plate 17, Fig. 4, are of comparatively rare occurrence. Almost invariably the crystals are twinned, and this twinning is indeed a very characteristic feature of the mineral. A six-rayed arrangement of platy crystals is very often to be recognised. Fibrous aggregates of needle-like crystals (Plate 18, Fig. 4) are not uncommon, while granular and compact forms are also frequent.

Besides the twinning, cerussite possesses several other characteristic features which enable it to be readily identified. One of these is the adamantine lustre on the bright crystal faces; and another is the high specific gravity (6·5), which is remarkably high for a colourless, transparent mineral. If we have a white, very heavy, and fairly soft (H. = 3½) mineral which effervesces with acid, we may be sure that we are dealing with cerussite. The high specific gravity is of course due to the presence of lead, and beads of this metal are readily obtained by heating the mineral on charcoal before the blowpipe.

Cerussite occurs in the upper oxidised zones of metalliferous veins, having resulted by the action of carbonated waters on galena. In Plate 18, Fig. 4, the white fibrous cerussite is associated with brown limonite, the latter being a product of alteration of iron-pyrites; we have here two secondary minerals produced by the alteration of sulphide minerals in a metalliferous vein.

When met with in large quantities cerussite is an important ore of lead, containing, when pure, 83·5 per cent. of the metal. It is found in upper levels of most lead-mines, and is thus a fairly common mineral. Very fine specimens have been found at Broken Hill in New South Wales and at

Broken Hill in North-Western Rhodesia. The unusually fine crystallised specimen represented in Plate 17, Fig. 4, is from Badenweiler, in Baden; and that in Plate 18, Fig. 4, is from Monte Vecchio, in Sardinia.

Chessylite (Plate 19, Figs. 1 and 2).—In Plate 19 are represented two minerals, each consisting of copper carbonate combined with an excess of copper oxide and some water; that is, they are hydrated basic copper carbonates. They thus contain the same chemical elements; but these are combined together in different proportions, and we have, in fact, two quite distinct chemical compounds. The formula of chessylite is $2CuCO_3.Cu(OH)_2$, or $3CuO.2CO_2.H_2O$; while that of malachite is $CuCO_3.Cu(OH)_2$, or $2CuO.CO_2.H_2O$, there being rather more copper oxide and water in the latter. When pure, the two minerals contain respectively 55·2 and 57·4 per cent. of metallic copper.

Although there is only a slight difference in the chemical composition of these two minerals, yet they present a striking difference in their external appearance. Chessylite is of a bright blue colour, whilst malachite is emerald-green. They are both soft minerals (H. $= 3\frac{1}{2}$–4), and can be readily scratched with a knife; and being carbonates they both effervesce with acid, giving a green copper solution. Further, they frequently occur together, having been produced by the alteration, due to the action of carbonated waters, of other copper-bearing minerals, particularly copper-pyrites.

Chessylite receives its name from the locality—Chessy, near Lyons, in France—whence the best crystallised specimens are obtained. Another name also in common use for this species is azurite, in allusion to the characteristic azure-blue colour of the mineral. It crystallises in the monoclinic system, but although it nearly always occurs as crystals, these do not, as a rule, present any very characteristic form. In Fig. 1 are shown divergent groups of small prismatic crystals, and in Fig. 2 small, bright crystals are thickly clustered on the surface of the matrix; both these specimens are from Chessy. Good crystallised specimens of chessylite are also found in the Copper Queen mine and in other copper-mines in Arizona, and at Broken Hill in New South Wales.

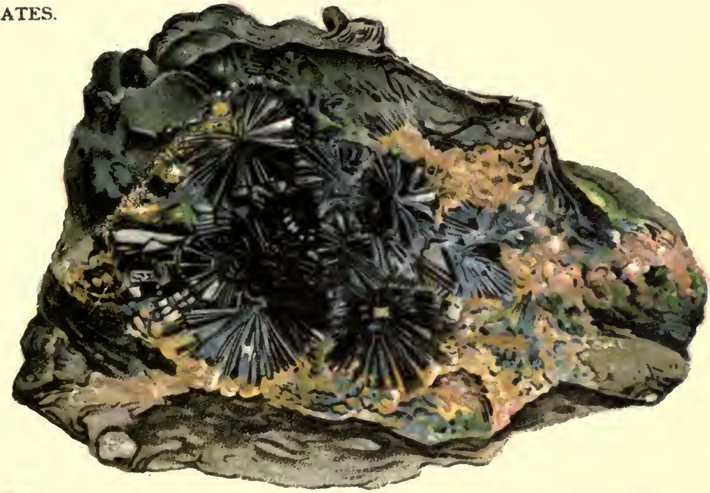
Although crystals are the most frequent, this mineral is also found as powdery or earthy masses of a bright sky-blue colour, the colour here being less dark than in the crystals. The streak, or powder, of the crystals is also sky-blue.

As already mentioned, chessylite frequently occurs in association with malachite, and in Figs. 1 and 2 are to be seen patches of green malachite with the blue chessylite. In Arizona the two minerals are sometimes banded together in compact masses, and specimens of this kind, when cut and polished, find a limited application in cheap jewellery.

Malachite (Plate 19, Figs. 3 and 4).—Whilst chessylite is usually found as crystals, on the other hand crystals of malachite are of rare occurrence. These are never very distinctly developed, usually having the form of fine needles grouped together in silky tufts. Ordinarily the mineral occurs as compact masses (Fig. 3), which may sometimes present rounded nodular (mamillary) surfaces (Fig. 4). These nodular masses when broken open or when cut and polished (as in Fig. 4) exhibit a concentric arrangement of lighter and darker green bands, together with a more or less distinct radially fibrous structure.

Malachite is a much more common mineral than chessylite, and it is the more stable of the two. This is proved by the fact that we often find crystals of chessylite altered to malachite—that is, pseudomorphs of malachite after chessylite. The green stains to be observed on the stones and ore from all copper-mines consist of malachite, this having been formed by the action of weathering agents on the other copper-bearing minerals of the ore. The green patina on bronze is also due to the surface alteration to malachite of the copper contained in the bronze; and on ancient bronze implements which have long been buried in the soil, nodular concretions of malachite are sometimes to be seen.

Large masses of compact malachite, sometimes weighing several tons, are found in the copper-mines of the Ural Mountains (Fig. 4), at Burra-Burra in South Australia, and in Arizona. Such material, especially that from Russia, is cut and polished for ornamental purposes, being made into vases and other small articles, or used for inlaying in table-tops and columns. The material is easily worked and may be turned in the lathe, and it takes a very good polish. When found in sufficiently large quantities, malachite is also of importance as an ore of copper.



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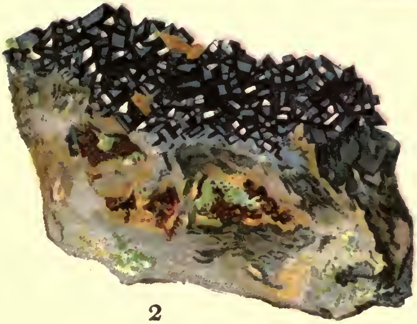

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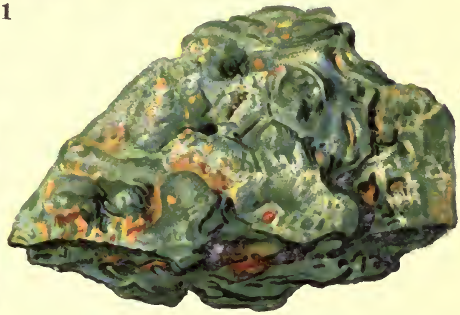

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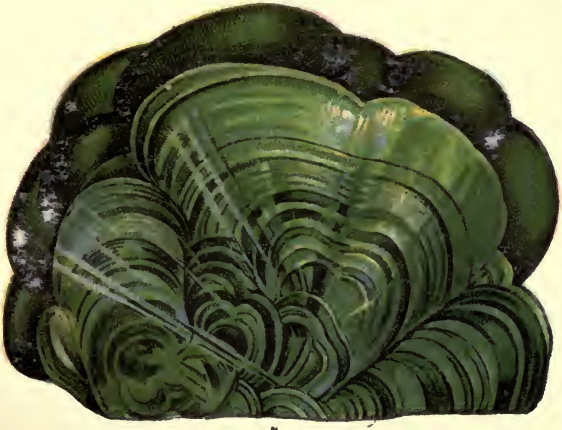

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1, 2, Chessylite. 3, 4, Malachite.

CHAPTER X.

The Sulphates, Chromates, Molybdates, and Tungstates.

In this group of oxygen-salts are brought together those minerals which contain in their acid portion the chemical elements sulphur, chromium, molybdenum, or tungsten, all of which, with the exception of sulphur, are themselves metals. These are closely related elements, falling in the sixth group of the chemists' periodic classification. Their salts can all be expressed by a similar chemical formula, which may be written generally as $R''MO_4$, when R'' is the metal and MO_4 the acid portion, M standing for one or other of the four elements named above. Some of the salts may contain in addition water of crystallisation.

The sulphates are the most important and numerous members of this group. These are combinations of a metal with the well-known sulphuric acid, or oil of vitriol. Thus, the mineral anglesite is lead sulphate, and the general formula given above here becomes $PbSO_4$. This formula is similar to that of galena (PbS) with the addition of four atoms of oxygen, and it is interesting to note that anglesite is formed in nature by the weathering and oxidation of galena.

All the minerals here considered, with the exception of gypsum (which contains water of crystallisation), are very heavy. They are often transparent and well crystallised, and are sometimes brightly coloured. Most of them are of economic importance.

Barytes (Plate 20, Figs. 1 and 2).—This is the sulphate of barium ($BaSO_4$). It is a common mineral, and one which is very often found as large, well-developed crystals. The crystals belong to the orthorhombic system, and they vary considerably in their habit, being tabular (Fig. 1) or prismatic (Fig. 2). The rhomb-shaped tabular crystals shown in Fig. 1 are bounded by the large basal plane, perpendicular to which are narrow faces of a rhombic prism forming the edges of the plates. The angles between the prism faces are 78½° and 101½°, these being also the plane angles of the rhomb forming the basal plane. The crystal shown in Fig. 2 is bounded by the same faces, with the addition of a macro-dome. Here the crystal is elongated in the direction of one of the horizontal crystallographic axes—the macro-axis, which in the picture is set up vertically. The two faces at the top of the crystal (one of them at the back, and therefore not visible in the picture), which slope away on either side from the upper line or ridge, are the faces of the rhombic prism, with an angle of 78½°. The long, narrow face in the front, and extending to the summit of the crystal, is the basal plane; and the two long faces on either side of this belong to a macro-dome. At the lower end of this crystal are to be seen a number of smaller crystals grown in parallel position with the main crystal.

A very important character of barytes is its cleavage, there being three directions in which the crystals may be readily split. The best cleavage is parallel to the basal plane, and on this surface the crystals frequently exhibit a pearly appearance, owing to the presence of cleavage cracks within the crystal. The two other rather less perfect cleavages are parallel to the two pairs of parallel prism faces; in the pictures, especially in Fig. 2, these cleavages are shown as cracks, running across the crystal parallel to the prism faces. Any crystal of barytes can be readily broken along these three cleavages into rhomb-shaped plates, similar to the crystals in Fig. 1. We have already seen that calcite also possesses three directions of perfect cleavage; but there is an important difference between the cleavage of calcite and barytes. In calcite the angle between any two of the cleavages is always the same; whilst in barytes the prism cleavages enclose an angle of 78½°, and these are each at 90° (i.e. at right angles) to the basal cleavage.

Another character of importance is the high specific gravity (4·5), and on this account the mineral is commonly known as heavy-spar. The hardness is about the same as that of calcite; so that the mineral can be readily scratched with a knife.

Barytes is often white or colourless, or various shades of yellow or brown; and the crystals may be quite transparent, or only translucent to opaque. In addition to crystals, platy or granular masses, showing larger or smaller cleavage surfaces when broken across, are of frequent occurrence.

In their general appearance, cleavage masses of white barytes are not unlike calcite; but the two minerals may be readily distinguished by their weight, by the angles between their cleavages, and by the fact that barytes does not effervesce with acids.

Barytes is usually found in veins, either alone or more often in association with metalliferous ores, especially ores of lead, and it is thus a common mineral in many mining districts. The specimen represented in Plate 20, Fig. 1, showing crystals of barytes resting on and partly penetrated by needles of stibnite (antimony-ore), is from the mines at Felsöbanya, in Hungary. The one shown in Fig. 2 is from the iron (red hæmatite) mines at Frizington, near Whitehaven, in Cumberland, where large and beautifully crystallised specimens are particularly abundant.

Barytes is used commercially for the manufacture of white paint, for which purpose it is often mixed with white lead. It is also used for giving weight and finish to certain kinds of paper. Much of the material mined under the name of barytes is really the more valuable mineral witherite, or carbonate of barium, and not the sulphate. This, being soluble in acids, is more readily converted into various barium compounds, which, amongst other uses, are employed in sugar-refining and for making rat poison.

Celestite (Plate 20, Fig. 4).—This is strontium sulphate ($SrSO_4$). In the form, angles, and cleavages of its orthorhombic crystals it presents the greatest similarity to barytes. These two minerals are, in fact, isomorphous; and belonging to the same group we also have the next mineral to be considered—namely, anglesite, or lead sulphate.

In Fig. 4 we have a parallel grouping of crystals of prismatic habit. These crystals are terminated at their upper ends by the prism faces, parallel to which are perfect cleavages, enclosing an angle of 76° (corresponding to the angle of 78½° in barytes). The vertical faces in the picture belong to a brachy-dome, and the small triangular faces on the corners belong to a macro-dome.

A characteristic, though not constant, feature of celestite is a faint bluish shade of colour (not greenish as in picture). It is on this account that the mineral receives its name, although the colour is never a deep sky-blue. White and yellowish crystals are also common.

Celestite is rather lighter (sp. gr. 4·0) than barytes, but its hardness is about the same. The best methods of distinguishing between these two minerals is afforded by the colours they impart to the non-luminous flame of a Bunsen-burner. A fragment of the mineral, moistened with hydrochloric acid, is supported on platinum wire in the flame, when celestite gives an intense crimson colour and barytes a pale yellowish-green, these being the characteristic flame colorations of all strontium and barium compounds respectively. On this property depends the use of celestite for producing the red fire of pyrotechnic displays. Another use for the strontium compounds obtained from celestite is in sugar-refining.

Fine crystallised specimens of celestite are abundant in the red marls of Triassic age in the neighbourhood of Bristol. Good crystals are also common in the sulphur-mines near Girgenti, in Sicily (Fig. 4); and very large bluish crystals are found in a limestone cave on Strontian Island in Lake Erie, North America.

Anglesite (Plate 20, Fig. 3).—Sulphate of lead ($PbSO_4$) is another orthorhombic mineral, belonging to the same isomorphous group with barytes and celestite. Its crystals are usually small and complex in form, and they are not always readily determined by mere inspection. The three crystals on the matrix in Fig. 3 are unusually perfect. Often the crystals are colourless and transparent, with a very brilliant and adamantine lustre. Being a lead mineral, it is very heavy (sp. gr. 6·3).

Anglesite is found in the upper weathered portions of lead-bearing veins, where it has been formed by the alteration of galena. In the old mine on Parys Mountain, in the island of Anglesey, minute crystals were found in abundance, encrusting the surface of cellular limonite, the latter being also a mineral of secondary origin. It is from this locality that the mineral receives its name. Good crystals have also been found in the lead-mines of Derbyshire, at Monteponi in Sardinia (Fig. 3), Broken Hill in New South Wales, and in Tasmania.

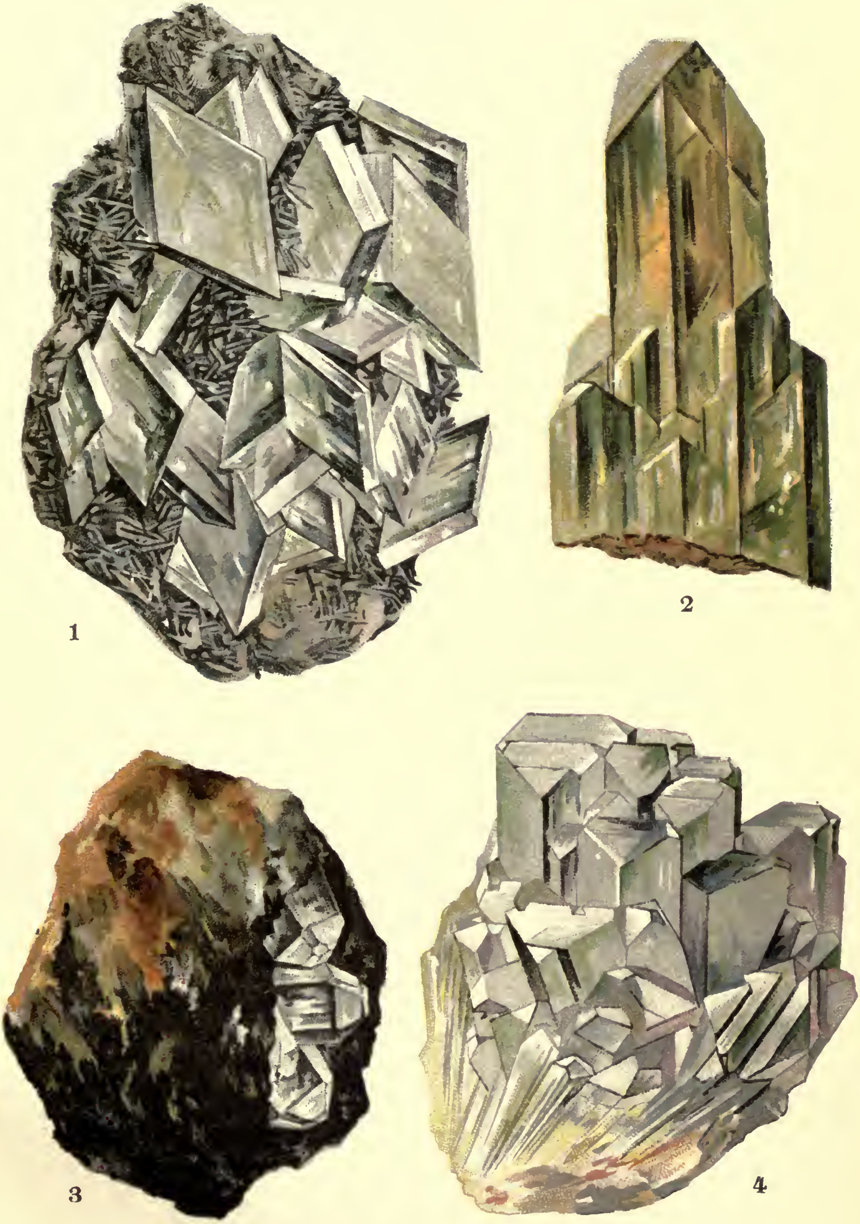
Gypsum (Plate 21, Figs. 1–3).—This is a common mineral of considerable practical importance. It is composed of calcium sulphate, with two molecules of water of crystallisation, the formula being $CaSO_4.2H_2O$.

Bearing this composition in mind, it is of interest to trace the chemical processes by which gypsum is formed in nature.

By the weathering of iron-pyrites, a mineral which as scattered grains and crystals occurs in rocks of almost every kind, sulphuric acid or iron sulphate is produced, and these compounds, being soluble in water, may be transported from their place of origin. Now if such solutions come into contact with limestone rocks or marls containing some calcium carbonate, a reaction takes place, the calcium of the rock combining with the sulphuric acid to form calcium sulphate. This new compound, being only slightly soluble in water, may be deposited as crystals of gypsum; but if a large excess of water is present, the whole of the calcium sulphate may be carried away in solution. In the latter case a hard water results, and one of which the hardness is permanent, since it cannot be removed by boiling or by the addition of lime, as may be done with a water rendered hard by the presence of calcium carbonate. Water containing much calcium sulphate in solution may under certain conditions collect in lakes, and with the gradual evaporation of the water gypsum may be deposited on the bed of the lake. By such a process vast beds of gypsum have been deposited in inland seas in past geological epochs, and it is such beds of gypsum that are quarried at the present day.

The formation of gypsum can readily be demonstrated experimentally. A fragment of calcite is dissolved in a drop of hydrochloric acid placed on a microscope slide, and to the solution of calcium chloride so obtained a drop of dilute sulphuric acid, or a fragment of any soluble sulphate, is added. The drop is then allowed to evaporate, when, under the microscope, crystals of gypsum may be observed in the process of growth. These crystals have the form of slender needles, with oblique terminations (as in Plate 21, Fig. 1), and they arrange themselves in pretty star-like groups.

Well-shaped crystals of gypsum are of common occurrence in nature, and when found embedded in clay, as is very



1, 2, Barytes. 3, Anglesite. 4, Celestite.

frequently the case, they are bounded on all sides by crystal-faces. The crystals represented in Plate 21, Fig. 1, being attached to the matrix, show faces at one end only. Gypsum crystallises in the monoclinic system, and the crystals possess only one plane of symmetry. The most usual form is as shown in Fig. 1; here the two larger crystals are tabular in habit parallel to the plane of symmetry, while the smaller crystals of the group are prismatic in habit. The faces present belong to clino-pinacoid (a pair of faces both parallel to the plane of symmetry), a rhombic prism (the two narrow faces placed vertically in the crystal forming the centre of the group), and a pyramid or dome (the two narrow faces placed obliquely at the top of the crystal).

Crystals of gypsum are often twinned, two crystals being grown together in such a position that they are symmetrical about a plane which truncates the front edge of the prism in Fig. 1. Such a twinned crystal is shown in Fig. 2.

Cleavage is a very important character of gypsum; the crystals can be split with great ease into thin leaves parallel to the plane of symmetry or clino-pinacoid. On this surface the lustre is often pearly in character, and there are frequently to be seen brightly coloured bands of the same nature as Newton's rings. The crystals also possess a characteristic fibrous cleavage parallel to the pair of dome faces, this cleavage being often shown by silky bands running obliquely across the surface of the perfect cleavage first mentioned.

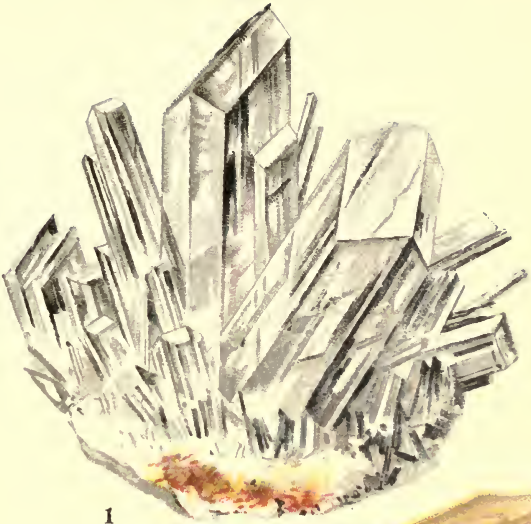
Crystals of gypsum are usually colourless and transparent, and only rarely do they show the yellowish colours often seen in massive gypsum. The name selenite, sometimes used for this species, is more correctly applied to the transparent crystals; this name refers to the somewhat fanciful resemblance of the lustre of the crystals to moonlight.

Another character of importance is the low degree of hardness (H. = 2). Gypsum is one of the few common, crystallised minerals that can be scratched with the finger-nail. The specific gravity (2·3) is also low. Other light and very soft minerals with a perfect cleavage, which may perhaps be mistaken for gypsum, are mica and talc. Cleavage flakes of gypsum, though flexible, are not elastic like mica, nor greasy to the touch like talc; and, further, they always show when bent the secondary fibrous cleavage.

Besides occurring as crystals, gypsum is frequently found as granular masses, forming enormous beds. Such material when fine-grained and compact is the well-known *alabaster*, which, owing to the softness of the mineral, particularly lends itself to carving. Fibrous masses are also common as a filling of veins, the fine fibres being arranged perpendicularly to the walls of the vein (Fig. 3). Such material (*satin-spar*), when cut and polished, with a rounded surface, displays a satiny lustre like cat's-eye (p. 90), and it is used for making beads and other small ornaments.

Good crystallised specimens of gypsum are found at very many places, and detached crystals are to be found embedded in most clays. The finest crystals are those from the salt-mines at Bex, in Switzerland, and the sulphur-mines near Girgenti, in Sicily. Large numbers of enormous crystals, a yard in length, have been found lining a cave in Utah. Extensive beds of massive gypsum are quarried in the neighbourhood of Paris, in Nottinghamshire and Staffordshire, and many other places. The material is heated in kilns to drive off a portion of the water of crystallisation, and thereby converted into the well-known plaster of Paris.

Linarite (Plate 21, Fig. 4).—Linarite is a very attractive though quite rare mineral, and one which is found at only a few localities. It is a basic sulphate of lead and copper of complex composition, the brilliant sky-blue colour being due to the presence of the latter element. The crystals are small, and have a bright lustre as well as a bright colour; in



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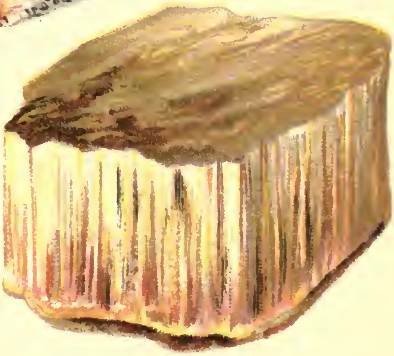

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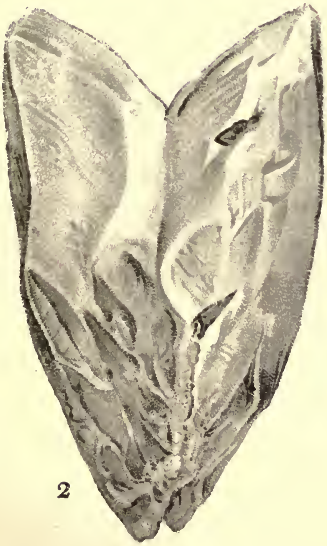

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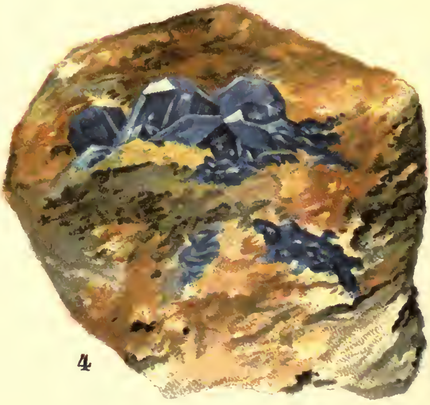


4

1—3, Gypsum. 4, Linarite.

general appearance they are not unlike crystals of chessylite. The specimen represented in Fig. 4 is from the old lead and copper mines of Roughten Gill, near Keswick, in Cumberland. Specimens have also been found at Leadhills, in Scotland, but, curiously, none at Linares, in Spain, from which place the mineral receives its name.

Crocoite (Plate 22, Fig. 1).—Chromate of lead ($PbCrO_4$) occurs in nature as beautiful crystals with a bright hyacinth-red colour and brilliant lustre, which in general appearance are not unlike crystals of the artificial salt potassium bichromate. Unfortunately the crystals lose their lustre and become dull on exposure to light, and in collections it is therefore necessary to keep them under cover. The crystals belong to the monoclinic system, and are usually prismatic in habit. In the picture (Fig. 1) are shown several prismatic crystals irregularly grouped on the surface of a piece of yellowish quartz. This specimen is from Beresov, in the Ural Mountains, where the mineral is found, together with galena, in veins of gold-bearing quartz. Magnificent groups of prismatic crystals several inches in length have recently been found in a lead-mine near Dundas, in Tasmania. Crocoite is a mineral of secondary origin, having been formed by the alteration of galena.

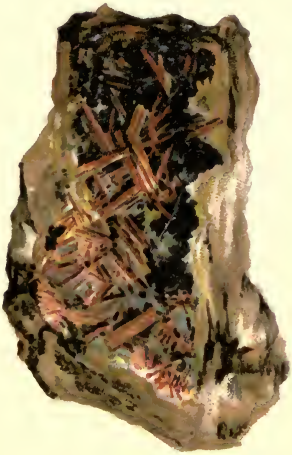
Wolframite (Plate 22, Fig. 2).—This mineral is a tungstate of iron and manganese, the two isomorphous molecules $FeWO_4$ and $MnWO_4$ being mixed together in variable proportions, so that the formula may be written as $(Fe,Mn)WO_4$. Here W is the chemical symbol of the metal tungsten, or wolfram. The mineral is very heavy (sp. gr. 7·1 to 7·5, varying with the proportion of iron and manganese), and opaque, with a dark brownish-black or pitch-black colour and a sub-metallic lustre.

Crystals of wolframite are rarely met with, while fine isolated crystals, such as that shown in Fig. 2, are quite exceptional. They are monoclinic, and possess a perfect cleavage in one direction parallel to the plane of symmetry. This perfect cleavage is always to be seen in the more commonly occurring granular or columnar masses, such as are often found embedded in quartz.

Wolframite often occurs in association with tin-stone (cassiterite)—for instance, in Cornwall, and at Zinnwald in Bohemia, the crystal in Fig. 2 being from the latter locality. Being both very heavy minerals, their separation is rather a troublesome operation for the tin-miner.

Sodium tungstate, prepared by fusing wolframite with soda, is employed in dyeing and for rendering fabrics non-inflammable. Metallic tungsten is used for the manufacture of the very hard and tough tungsten-steel; and quite recently, in the form of fine wire, it has been used for the filaments of the so-called 'osram' electric lamps.

Wulfenite (Plate 22, Fig. 3).—This name is not to be confused with the name of the mineral last described. It was given in honour of the eighteenth-century Austrian mineralogist Wulfen; whilst *wolfram* is an old German mining term meaning 'wolf froth.' Wulfenite is a molybdate of lead ($PbMoO_4$), crystallising in the tetragonal system. The crystals almost always have the form of square plates with bevelled edges, and sometimes the corners also are replaced by narrow pyramidal faces (Fig. 3). The crystals are often of a yellowish or greyish colour, but sometimes they are bright orange-yellow or orange-red, with a brilliant lustre. The mineral is one of secondary origin, having been formed by the alteration of galena in veins of lead-ore. The earliest known locality, and one that has produced a large number of good specimens, is Bleiberg (meaning, in German, 'lead mountain'), in Carinthia; while very fine groups of crystals of richer colours have been found in Arizona (Fig. 3) and Utah.



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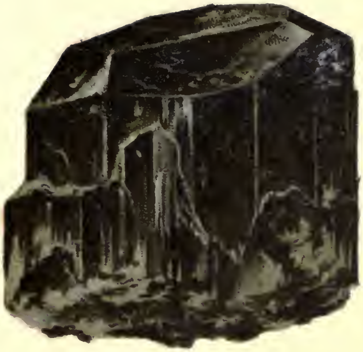

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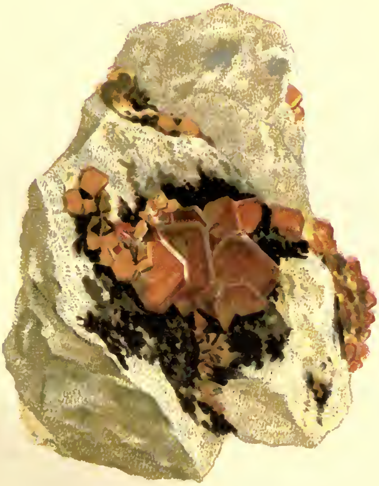

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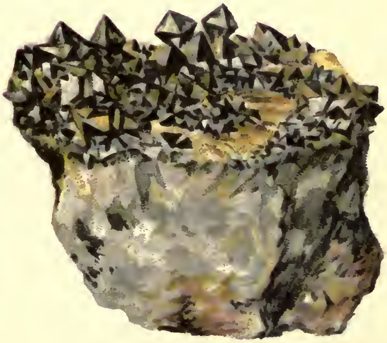

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1, Crocoite. 2, Wolframite. 3, Wulfenite. 4, Scheelite.

Scheelite (Plate 22, Fig. 4).—It was in this mineral that the Swedish chemist Scheele discovered, in the year 1781, the element tungsten. The mineral itself had previously been known as tungsten, which means, in Swedish, 'heavy stone,' and it was afterwards renamed scheelite in honour of Scheele. Chemically, it is a tungstate of calcium ($CaWO_4$), and it is isomorphous with the molybdate of lead, wulfenite. Its crystals are tetragonal; but instead of being tabular in habit like crystals of wulfenite, they are pyramidal, having the form of square pyramids. The crystals are white, greyish, or yellowish in colour, and sometimes almost transparent. To all appearance they might be expected to be quite light, but when a crystal of scheelite is handled it will be found to be surprisingly heavy (sp. gr. 6·0).

Scheelite often occurs in association with wolframite and tin-stone, and it is also met with in granitic veins, sometimes together with gold. Good crystals have been found at Tavistock, in Devonshire, and at Carrock Fell, in Cumberland. The picture (Fig. 4) shows a number of small crystals of the characteristic form and colour scattered over the surface of a matrix of quartz; this specimen, like the specimen of wolframite in Fig. 2, is from the tin-mines at Zinnwald, in Bohemia.

CHAPTER XI.

The Phosphates, Arsenates, and Vanadates.

THE phosphates, which are by far the most important members of this group, are salts of phosphoric acid, the chemical formula of which is H_3PO_4. The non-metallic and highly inflammable element phosphorus is here combined with oxygen and hydrogen, and when this hydrogen is replaced by a metal we have a salt called a phosphate.

Phosphates are of great importance in the economy of nature, for they enter into the composition of plants and animals, and bones are composed largely of calcium phosphate together with calcium carbonate. These phosphates are all indirectly of mineral origin, having been extracted from the soil by growing vegetation. On this account the mineral apatite, to be presently described, is largely used in the manufacture of artificial manures, or fertilisers. Another phosphate—namely, turquoise—is a valuable precious stone; while still another (pyromorphite) is an ore of lead. We thus see that the mineral phosphates are of considerable importance. Many of the numerous species, of which no mention need be made in this book, are of quite rare occurrence, and of interest only to the mineralogist and crystallographer. In addition to phosphate, several of the minerals of this group contain water of crystallisation, or some other constituent.

Closely related to the phosphates, and strictly isomorphous with them, we have the arsenates, antimonates, and vanadates. In these salts the place of phosphorus is taken by the chemically related elements arsenic, antimony, or vanadium, which, though metallic elements, here play the part of acids. The chemical formula of all the salts is of the same type; for instance, arsenic acid is H_3AsO_4, and vanadic acid is H_3VO_4.

Apatite (Plate 23, Fig. 1).—The name apatite means, in Greek, 'to deceive,' because this mineral is often mistaken for other species; indeed, some eminent mineralogists have described as new minerals material which afterwards proved to be merely apatite. The name also suggests a certain class of humour; the announcement a few years ago of an American dealer ran: 'Minerals for presents: send your friend an "apatite" for his Christmas dinner.'

In its chemical composition apatite is somewhat complex; it is essentially a phosphate of calcium, but in combination with this we have a small proportion of calcium fluoride, or calcium chloride, and the formula becomes $3Ca_3(PO_4)_2.CaF_2$, or $(CaF)Ca_4(PO_4)_3$. This is fluor-apatite, and the formula of the corresponding compound chlor-apatite is $3Ca_3(PO_4)_2.CaCl_2$. We thus have two varieties of apatite, but these can only be distinguished by chemical tests.

Apatite is often found beautifully crystallised. The crystals have the form of a hexagonal prism, terminated at each end by six-sided basal planes placed at right angles to the six faces of the prism. The prism may be either short (Fig. 1) or long (as in Fig. 3, of pyromorphite), and the habit of crystals, therefore, either tabular or prismatic. Occasionally the edges between the prism and the base are replaced by narrow faces of hexagonal pyramids, and the corners by other small facets. The faces on the corners are arranged in a peculiar manner, which is very characteristic of crystals of apatite; they are present on only one side, not both sides, of each edge of the prism, and the crystals are therefore said to be hemihedral.

Crystals of apatite may be colourless and transparent or white and opaque; often they are of a greenish or brownish shade of colour, or sometimes they are sky-blue or violet

(Fig. 1). The crystals possess no cleavage, and their fracture is sub-conchoidal. In addition to crystals, compact and earthy masses are of abundant occurrence. This form of the mineral is known as *phosphorite*, or rock-phosphate, and being found in large beds, it is extensively mined for the manufacture of the compound called superphosphate of lime, which, being soluble in water, can be directly assimilated by plants.

The hardness of apatite is No. 5 on the scale; the crystallised material can be scratched with a knife, though not very easily; earthy masses may, however, be quite soft. This degree of hardness affords an easy means of distinguishing crystals of apatite from the hexagonal crystals of other minerals (beryl, tourmaline, quartz), which may somewhat resemble apatite in appearance. The specific gravity (3·2) also serves for distinguishing apatite. But in case of doubt the only sure way is to test the material chemically for phosphoric acid and calcium.

Apatite is a mineral of wide distribution. It is present in small amount as minute crystals in all igneous and crystalline rocks; and in veins traversing granite and gneiss it is sometimes found as beautiful crystals. It also occurs in metalliferous veins, especially in those containing tin-ore. The specimen represented in Fig. 1 is from a tin-mine at Greifenstein, near Ehrenfriedersdorf, in Saxony; the brilliant and transparent violet crystals here encrust crevices in an altered granitic rock known as greisen. The extensive apatite deposits of southern Norway occur in connection with a rock called gabbro; while those of Canada are in crystalline limestone. Many of the rock-phosphates are of recent formation, and have been derived by the action of bird guano on limestone, often a coral limestone on small islands frequented by large flocks of birds.

Pyromorphite (Plate 23, Figs. 2 and 3).—This ore of lead is analogous to, and isomorphous with, apatite, the formula being $3Pb_3(PO_4)_2.PbCl_2$, or $(PbCl)Pb_4(PO_4)_3$—that is, just the same as the formula of chlor-apatite, with lead in place of calcium. The crystals are also extremely similar, though in pyromorphite faces other than the hexagonal prism and the base are only rarely present. In the group of crystals shown in Fig. 3 this characteristic form is plainly to be seen; while in Fig. 2 the prisms are longer and more closely aggregated. Only rarely do the crystals show any degree of transparency; but they are usually prettily coloured, being wax-yellow, orange-yellow, brown (Fig 3), or bright grass-green (Fig. 2). On this account the mineral is variously known to miners as 'brown lead-ore,' 'green lead-ore,' or 'variegated lead-ore.' Since it contains a large amount of lead (76½ per cent.), the mineral is very heavy (sp. gr. 7·0).

Pyromorphite occurs in veins of lead-ore, where it has been formed by the alteration of galena; the phosphate solutions producing the change have perhaps in some cases been derived from the surface soil or from guano deposits. Good crystallised specimens have been found in Cornwall; the specimen represented in Fig. 2 is from Hofsgrund, in Baden, and that in Fig. 3 is from the Friedrichssegen mine, near Ems, in Nassau.

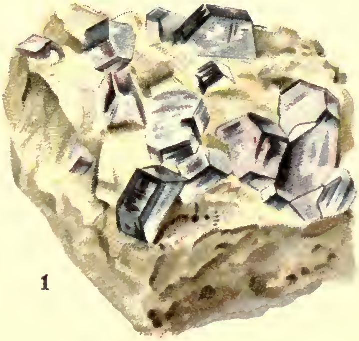
Another ore of lead very similar in appearance to pyromorphite is known as *mimetite*, this being the corresponding arsenic compound with the formula $3Pb_3(AsO_4)_2.PbCl_2$. The crystals are very like those of pyromorphite, but are often much curved, having the appearance of barrels or small balls. Abundance of crystals of this kind (known by the name of campylite) are to be found among the old mine refuse in Dry Gill, a deep valley on the side of Carrock Fell, in Cumberland.

Vanadinite (Plate 23, Fig. 4).—This is still another mineral of the same isomorphous group of minerals, with the analogous formula $3Pb_3(VO_4)_2.PbCl_2$, the phosphorus of pyromorphite being here replaced by the rare metal vanadium. This mineral was formerly found as brown crystals and small warty masses at Wanlockhead, in Scotland; and more recently very brilliant ruby-red crystals have come from Arizona (Fig. 4). In the picture there are to be seen several small hexagonal prisms, with six-sided planes at their ends, scattered over the surface of the matrix. Like pyromorphite and mimetite, this mineral is of secondary origin in veins of lead-ore.

Erythrite (Plate 23, Figs. 5 and 6).—We pass now to another isomorphous group of minerals known as the vivianite group, for the several members of which the formula may be written generally as $R''_3Q_2O_8.8H_2O$, where the metal R'' may be iron, cobalt, nickel, zinc, or magnesium, and Q stands for either phosphorus or arsenic. The type mineral (vivianite) of this group will be described presently; the one to be now considered is erythrite, the hydrated arsenate of cobalt, in which the general formula becomes $Co_3As_2O_8.8H_2O$.

The name erythrite, meaning 'red' in Greek, refers to the characteristic crimson or peach-blossom-red colour of the mineral. The mineral could not be confused with the kind of sugar of the same name, though the identity in name is certainly confusing. Another name often applied to the mineral is cobalt-bloom.

Crystals of erythrite are small and comparatively rare. They are monoclinic and have the form of needles or small blades, and are usually arranged in radiating tufts or star-like groups. They possess a highly perfect cleavage in one direction parallel to the plane of symmetry, and on this surface the lustre is often beautifully pearly. In Fig. 6 is shown a number of crimson crystals scattered over the surface of white quartz.



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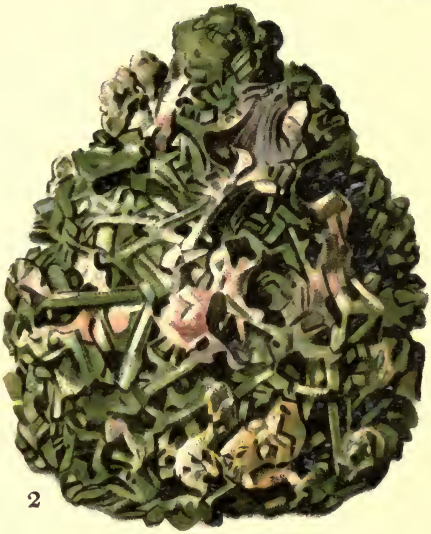

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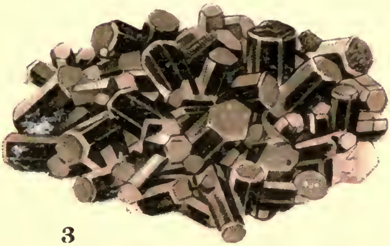

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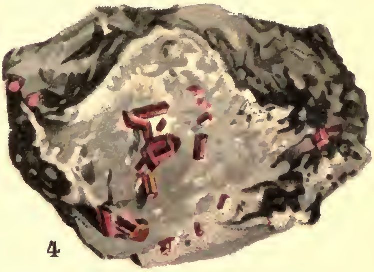

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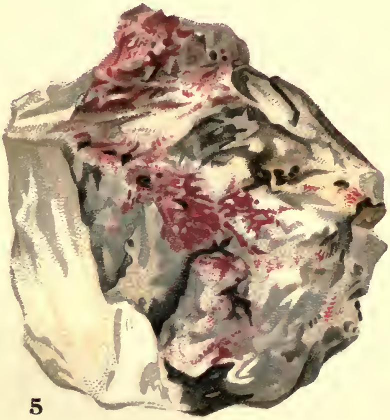

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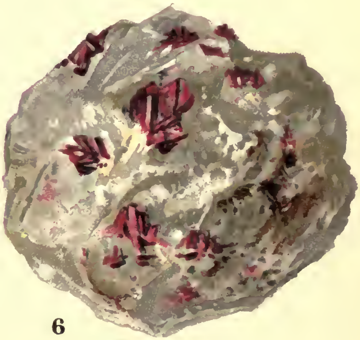

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1, Apatite. 2, 3, Pyromorphite. 4, Vanadinite. 5, 6, Erythrite.

Much more frequent than crystals are earthy or powdery masses of the same beautiful colour, which are to be seen as encrustations on most specimens of cobalt-ore. The mineral, in fact, owes its origin to the weathering of cobalt arsenide (smaltite, p. 75). Occurring mixed in this manner with cobalt-ore, it is used for the manufacture of cobalt-blue, so that from a mineral of a bright crimson colour there is obtained a beautiful sky-blue product. The two specimens represented in Figs. 5 and 6 are both from Schneeberg, in Saxony.

Analogous to cobalt-bloom we have the corresponding nickel compound, $Ni_3As_2O_8.8H_2O$, known as *annabergite*, or nickel-bloom. This is of a characteristic pale apple-green colour, and in the same way it is produced by the weathering of nickel arsenide, or niccolite (p. 68); a small quantity of nickel-bloom is shown on the specimen of niccolite in Plate 6, Fig. 1.

Wavellite (Plate 24, Fig. 1).—This is a hydrated basic phosphate of aluminium, with the formula $2AlPO_4.Al(OH)_3.4\frac{1}{2}H_2O$. Distinct crystals are extremely rare, and almost always this mineral is found as hemispherical or globular forms attached to the surface of slaty rocks. When these nodules are broken across they show in the interior a beautiful radiated or star-like structure, due to the close grouping of acicular crystals around a centre. This form and structure, together with the greenish or greenish-yellow colour, is indeed a very characteristic feature of the mineral.

Wavellite, though abundant at certain localities, is not met with at many spots. It was first found by Dr W. Wavel (after whom it was named), at the end of the eighteenth century, in crevices of a black slaty rock near Barnstaple, in Devonshire. It has also been found in Ireland, and at Magnet Cove, in Arkansas, the specimen in Fig. 1 being from the latter locality.

Lazulite (Plate 24, Fig. 2).—This also is a phosphate of aluminium, but one which contains, in addition, some iron and magnesium, the formula being $2AlPO_4.(Fe,Mg)(OH)_2$. As the name implies, this mineral is of an azure-blue colour, and so also is the mineral lazurite. It is therefore necessary to distinguish carefully between these two deep-blue minerals; lazurite will be described farther on amongst the silicates (p. 161).

Lazulite is found as sharp, clean-cut crystals embedded in quartz. These crystals have very much the appearance of square tetragonal pyramids (Fig. 2), but in reality they are monoclinic, with only one plane of symmetry. It is a comparatively rare mineral, found at only a few localities. The best specimens are from Werfen, in Salzburg, and Graves Mt., in Lincoln Co., Georgia. The specimen figured is from the American locality, and shows the crystals, with their characteristic form and colour, embedded in quartz.

Cuprouranite (Plate 24, Fig. 3).—Cuprouranite, or torbernite, is the typical representative of an isomorphous group of minerals known as the 'uranium micas,' so called because they contain uranium and form thin, platy crystals, with a perfect cleavage like the micas. They are all phosphates, or arsenates of uranium with copper or calcium, and water of crystallisation. Like all compounds of uranium, they are radio-active (p. 103).

Cuprouranite is the hydrated phosphate of uranium and copper, with the complex formula $CuO.2UO_2.P_2O_5.8H_2O$. Its crystals belong to the tetragonal system, and have the form of thin, square plates, with a perfect micaceous cleavage parallel to the surface of the plate. On this surface the lustre is consequently pearly in character. The colour is always a bright grass-green (much more vivid than represented in Fig. 3). The crystals are quite soft, being only slightly harder than gypsum.

Very beautiful crystallised specimens have been found near the surface in some of the Cornish mines—namely, near Calstock, Grampound Road, and Redruth. The crystals are deposited on limonite (as in Fig. 3, from Cornwall), and they evidently have been formed by the alteration of the pitchblende and copper ores found at greater depths in the same mines.

Another of the 'uranium micas' is the mineral *calcouranite*, or autunite, which has the same chemical composition as cuprouranite, except that calcium takes the place of copper. This crystallises in thin, square plates of a sulphur-yellow colour, sometimes with a greenish tinge. It is found at Autun in France (hence the name autunite), at Sabugal in Portugal, and some other places, often as a coating on the surface of crevices in weathered granite. In Portugal it has quite recently been mined as an ore of radium, one gram of which is extracted from 600 tons of the crude ore—that is, one part in 600 million.

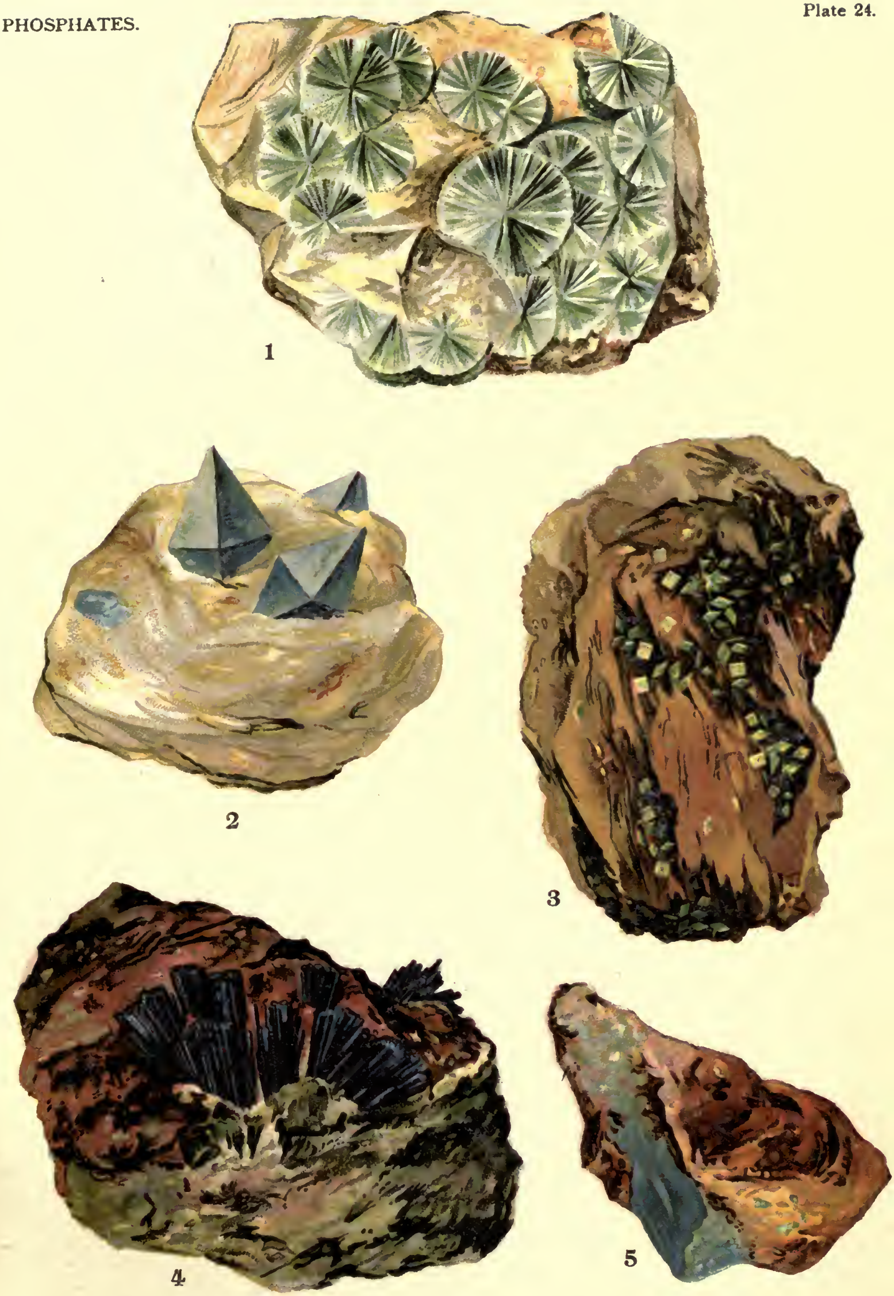
Vivianite (Plate 24, Fig. 4).—It has already been mentioned that vivianite is the type member of an isomorphous group of minerals, to which erythrite and annabergite also belong (p. 136). In this group vivianite is the hydrated phosphate of iron (ferrous iron), with the formula $Fe_3(PO_4)_2.8H_2O$. Its crystals are monoclinic, usually with a prismatic or blade-like habit; they have a very perfect cleavage parallel to the plane of symmetry, and on this surface the lustre is pearly. The crystals are very soft, and are easily bent and distorted. The characteristic colour is deep indigo-blue, though sometimes it is greenish-blue. When, however, a rock-cavity containing crystals of vivianite is freshly broken open, the crystals are colourless and transparent, but on exposure to air and light they very quickly become blue, this change being due to a partial alteration of the ferrous iron to ferric iron. For this reason the crystals to be seen in collections are always blue, and probably but few mineralogists have had an opportunity of seeing the colourless crystals.

The specimen represented in Fig. 4 shows bundles of prismatic crystals grown in a cavity in massive pyrrhotite which in part has been altered to limonite. Many fine specimens of this kind were found years ago in a mine called Wheal Jane, near Truro, in Cornwall. Groups of larger crystals have been more recently found at Leadville, in Colorado.

Crystallised vivianite is, however, of comparatively rare occurrence; but in the form of a pale-blue powder, known as blue-iron-earth, this mineral is of wide distribution, being found in practically all peat-bogs and deposits of bog-iron-ore, and especially on bones and horns buried in such bogs. It is also sometimes found encrusting the roots of plants when these are embedded in a ferruginous clay.

Turquoise (Plate 24, Fig. 5).—As a precious stone turquoise is known to everybody, but probably few are aware that in chemical composition it is a hydrated phosphate of aluminium coloured by copper and iron compounds. The exact composition is, however, rather doubtful, but the proportions are different from those of wavellite (p. 137) and the several other hydrated phosphates of aluminium that occur as minerals. In turquoise there is usually about 5 per cent. of copper oxide.

Although showing under the miscroscope a minutely crystalline and granular structure, turquoise is never found as crystals, but only as nodular masses, or more usually as a compact mineral, filling crevices in rocks, thus resembling opal in its mode of occurrence. It is an opaque mineral, which, when cut, takes a good polish, and its use as a precious stone depends on its pure sky-blue colour and soft, waxy lustre. For use in jewellery it is always cut with a convex surface, and when mounted with a surround of small diamonds



1, Wavellite. 2, Lazulite. 3, Cuprouranite. 4, Vivianite. 5, Turquoise.

it is very effective. Very clever imitations, so far as colour goes, are made in glass, but these do not show quite the true lustre of the genuine stone, and they have a transparent, glassy appearance, which is especially seen when a fragment is broken off. The natural mineral is often of a greenish colour; but such stones, though at one time in favour, are now of very little value.

The best turquoises come from near Meshed, in Persia, where they occur as a filling in crevices in a weathered rock of igneous origin. Here the mineral has been mined for hundreds of years, and being exported to the west through Turkey, it came to be known as turquoise. In the Sinai Peninsula, turquoise-mines were worked by the ancient Egyptians, and the stone was employed by them as a material for carving scarabs. Ancient mines, worked in prehistoric times, are situated in New Mexico and other western states of North America, and at the present day very fine turquoises are obtained from this region; the colour of some of the American stones is, however, rather liable to fade on exposure to light.

CHAPTER XII.

The Silicates.

THE group of silicates is by far the largest, and at the same time the most complex, in our chemical classification of minerals. Although a good number of species are here described, yet there are a great many more known to mineralogists, several of which are, however, only of scientific interest. The abundance and complexity of silicon compounds in the inorganic world is in a way analogous to the vast number of complex carbon compounds in the organic world. It is interesting to note that these two non-metallic elements, carbon and silicon, occupy adjacent positions in the same group of the chemists' periodic classification of the elements; in other words, these elements are closely related in their chemical properties. The ultimate product, resulting by the destruction of organic compounds, is the common gas carbon dioxide; and, similarly, the ultimate product produced by the weathering and disintegration of silicon compounds is silicon dioxide, which has been already described as the common minerals quartz and opal.

Silicon dioxide, or silica, when combined with water, gives an acid known as silicic acid, which can be prepared in the laboratory as a gelatinous substance. The proportions of water and silica may vary: thus in meta-silicic acid ($H_2O + SiO_2 = H_2SiO_3$) we have equal molecular proportions —one molecule of water combined with one molecule of silica; while in ortho-silicic acid ($2H_2O + SiO_2 = H_4SiO_4$) they are in the ratio of two to one. Several other hypothetical silicic acids have to be assumed to explain the chemical composition of various silicates which occur in nature as minerals. The formulæ used to express the chemical composition of these minerals are often very complex, and in some cases not yet completely determined by mineral chemists. It would, therefore, be out of place in this book to enter into much detail in this direction, and we must content ourselves by stating the principal elements that are present in the more complex minerals.

The simple silicates of the alkali metals—for example, sodium silicate and potassium silicate (known as water-glass)—are soluble in water. But all the naturally occurring silicates are insoluble in water, and most of them are unattacked by acids (except hydrofluoric acid); further, they can be fused only with great difficulty. On the other hand, the compounds of carbon are more readily dealt with and can be prepared in the laboratory; so that by a variety of reactions and replacements the organic chemist is able to draw conclusions as to the chemical constitution of such compounds. The mineral chemist is, however, placed at a disadvantage by reason of the intractable nature of the material he has to deal with. For instance, the usual way of decomposing a silicate for analysis is to fuse the finely powdered mineral with sodium carbonate in a platinum crucible over the intense flame of a blowpipe. Mineral silicates can be prepared artificially only with great difficulty at very high temperatures, and even when the experiments extend over a period of several days only crystals of microscopic dimensions are obtained. The element of time is here a matter of consequence; and in nature's laboratory, where high temperatures and pressures are available for long periods, very finely crystallised products result—indeed, amongst the silicates we find some of the most beautiful of crystallisations.

It is not surprising, therefore, that but little knowledge has been acquired respecting the chemical constitution of naturally occurring silicates. And for this reason no really satisfactory classification of the whole group has yet been devised, different authors using different systems of classification. Nevertheless, certain closely related species fall naturally together into a number of isomorphous groups. In the following pages some of these groups will be considered; while some other species must be dealt with singly in no particular order.

The silicates are of prime importance as rock-forming minerals, since they form the bulk of the rocks of the earth's crust. All the rocks of igneous and metamorphic origin are composed almost entirely of silicates, sometimes with the addition of quartz; and it is only in certain rocks of sedimentary origin, such as limestone and the purer quartz-sandstones, that they are absent. The silicates are also of importance from other points of view. Several species are used as precious stones or for ornamental purposes; while others have important technical applications.

The Felspar Group.

This is a very important group of rock-forming minerals, which are analogous in chemical composition and similar in crystalline form; that is, they form an isomorphous group. They are silicates of aluminium, together with either potassium, sodium, or calcium; so that, chemically, we have three kinds of felspar—namely, potash-felspar, soda-felspar, and lime-felspar. Again, although very similar to one another in the form of their crystals, yet these belong to two different systems, the monoclinic and the triclinic. We may, therefore, divide the felspars into monoclinic felspars and triclinic felspars.

A character of special importance, and one common to all kinds of felspar, is that of cleavage. The crystals possess a perfect cleavage parallel to the basal pinacoid, this being called the basal cleavage; and a second, rather less perfect cleavage, parallel to the brachy-pinacoid, called the brachy-pinacoidal cleavage. Now in monoclinic felspar the second cleavage is parallel to the single plane of symmetry, which is perpendicular to the basal plane. The two directions of cleavage are here, therefore, at right angles to one another, and this kind of felspar is consequently called *orthoclase*, meaning, in Greek, splitting at right angles. In the triclinic felspars, on the other hand, the two cleavages are not quite at right angles, but inclined at an angle varying in the different species from 86° 24′ (albite) to 85° 50′ (anorthite); these are therefore referred to collectively as *plagioclase*, which means splitting obliquely. In addition to these we have another kind of triclinic felspar known as *microcline*, so called because the angle between the cleavages differs only very slightly from a right angle, being about 89° 30′.

The various kinds of felspar may now be tabulated as follows:

	Chemical Formula.	System of Crystallisation.
Orthoclase, or potash-felspar .	$KAlSi_3O_8$.	Monoclinic.
Microcline, or potash-felspar .	$KAlSi_3O_8$.	Triclinic.
Albite, or soda-felspar . . .	$NaAlSi_3O_8$.	Triclinic.
Anorthite, or lime-felspar . .	$CaAl_2Si_2O_8$.	Triclinic.

By the mixing together of albite and anorthite in indefinite proportions, we have other members of the plagioclase series, which are known as oligoclase, andesine, and labradorite; these are intermediate between albite and anorthite, not only in chemical composition, but in all their properties.

Twinned crystals are of very frequent occurrence in all the felspars, and several types of twinning are known. The plagioclase felspars are invariably twinned according to the 'albite law,' one portion of a twinned crystal being a reflection of the other portion across a plane—the twin-plane—parallel to the brachy-pinacoid. In one and the same crystal this twinning is repeated many times, so that the whole crystal consists of a pile of twin-lamellæ. This repeated lamellar twinning gives rise to a very characteristic appearance, to be seen when basal cleavage flakes, or thin sections of plagioclase crystals, are examined in polarised light under the microscope. Further, it gives rise to a system of fine lines on the basal plane and also on the basal cleavage; these lines or striations being parallel to the edge between the basal plane and the brachy-pinacoid. On this account the plagioclase felspars are known also as 'striated felspars'; and in hand-specimens they can always be recognised by this character.

In addition to similarity of crystalline form and cleavage, the felspars all possess the same degree of hardness (No. 6 on the scale). They may be colourless and transparent, but more often are white or pinkish and opaque. They are not heavy, the specific gravity ranging with the chemical composition from 2·55 (orthoclase) to 2·75 (anorthite). If, therefore, we have a white, opaque mineral with two good cleavages, nearly or quite at right angles, which is not heavy, and can only just be scratched with a knife, we may be pretty sure that the mineral in question is felspar.

There are extremely few kinds of igneous rocks and gneisses which do not contain a large proportion of one or other of the felspars; so that these minerals are abundant and of wide distribution. By the weathering and breaking down of these rocks the felspars are decomposed, their alkalis being assimilated by plants or carried away in solution; while the alumina and silica combine with water to form hydrated aluminium silicate. The latter, together with other mineral particles, may be removed by running water and deposited as beds of clay, such as is used for the making of bricks and pottery. A purer form of white clay, known as china-clay, or kaolin, also results from the decomposition under special conditions of the felspar of granite.

We thus see that, indirectly at least, the felspars are of considerable economic importance.

Orthoclase (Plate 25, Figs. 1 and 2).—This is potash-felspar, crystallising in the monoclinic system. It is the most abundant of the felspars, and the one most commonly found as large, well-formed crystals. For this reason it is sometimes called 'common felspar.' It is an important constituent of all granites and syenites, of the lavas known as rhyolite and trachyte, and of several other kinds of igneous rocks, more especially those which also contain some quartz. It is also abundant in gneisses; and sometimes it is present in the sandstones and grits which have been formed of the debris of such rocks. The pegmatite-veins associated with granitic masses consist largely of coarsely crystallised orthoclase. Cavities in granite, and more especially in pegmatite, are often lined with well-formed crystals of orthoclase, together with crystals of topaz, tourmaline, and other minerals.

In Plate 25, Fig. 1, is shown a group of orthoclase crystals, and in Fig. 2 a single crystal, taken from a cavity in the granite at Alabashka, near Mursinka, in the Urals. In both specimens the reddish felspar is associated with smoky-quartz; and in Fig. 2 there is a regular interpenetration of the two minerals. The crystals here represented are bounded by a rhombic prism, the clino-pinacoid (on the right in Fig. 2), and the basal plane and an ortho-pinacoid at the top.

The crystals from granite have frequently a dull, chalky or stony appearance; but certain crystals have quite the appearance of glass, and are thus known as glassy felspar, or ice-spar, or more commonly as *sanidine.* Crystals of sanidine are found embedded in the trachytic lavas of the Rhenish district. Clear crystals of the variety called *adularia* are found lining crevices in the gneissic rocks of the Swiss Alps. Still another variety of orthoclase is that known as *moon-stone*, so called because of the moon-like reflection, or opalescence, seen on its surface. Such stones are found plentifully in Ceylon, and are cut and polished, with a rounded surface, for use in jewellery. Rarely to be seen in orthoclase are the brilliant blue, green, or yellow sheens, or coloured reflections, of the same nature as those characteristic of labradorite (p. 150); material of this kind forms a large part of the augite-syenite of Laurvik and Fredriksvärn, in southern Norway, a rock which, when cut into slabs and polished, is extensively used for ornamental purposes.

Large quantities of orthoclase are quarried from the pegmatite-veins of southern Norway, the material being used in the manufacture of porcelain, more especially for the production of the glaze.

Microcline (Plate 25, Fig. 4).—This also is potash-felspar, and is identical, chemically, with orthoclase. Crystallographically, however, it is triclinic, whilst orthoclase is monoclinic; so that these two species are to be considered as dimorphic forms of potash-felspar. In their external appearance, however, crystals of microcline cannot be distinguished from crystals of orthoclase, and indeed the only method of distinguishing the two is by means of their optical characters as observed under the polarising microscope. Basal cleavage flakes or thin sections of microcline show in polarised light a very characteristic cross-hatched structure, due to repeated lamellar twinning in two directions. Orthoclase and microcline are thus only to be distinguished by special optical tests, and the difference between them seems to be a matter of only slight importance, and especially so when we bear in mind that they occur in nature under exactly the same conditions as constituents of granite and pegmatite. Indeed, many mineralogists assert that they are in reality identical, the cross-hatching being on so minute a scale in orthoclase that it is not visible even under the higher powers of the polarising microscope. This ultra-microscopic twinning would account for the observed differences in the optical characters of orthoclase and microcline.

A beautiful green variety of microcline deserves special mention. This is known as *amazon-stone* (Fig. 4); it is found as large, well-shaped crystals in cavities in granite at a few places, the specimen represented in the picture being from Pike's Peak, in Colorado. Here we have a parallel intergrowth of two crystals, each bounded by a rhombic prism, clino-pinacoid, and at the top by the basal plane and an ortho-pinacoid. Amazon-stone is sometimes cut and polished for the construction of various small ornamental objects.

Albite.—Mention has already been made of the plagioclase felspars, which form a continuous isomorphous series, ranging from albite to anorthite. The soda-felspar called albite, which forms one end of this series, is of importance as a rock-making mineral, and it is also of interest to collectors as being found in pretty groups of white crystals. Such crystals are found, together with clear crystals of quartz (rock-crystal), attached to the walls of crevices in the gneissic rocks of the Alps and in the slates at Tintagel, in Cornwall. The name albite refers to the white colour of the crystals.

Oligoclase is an intermediate member of the plagioclase series of felspars, consisting of a mixture of three to six parts of albite with one part of anorthite. It is to this species that the beautiful variety known as *sun-stone*, or avanturine felspar, belongs. This shows on its surface a very pretty metallic spangled reflection, due to the enclosure in the stone of numerous small scales of hæmatite. The best specimens—such as are cut and polished for use in jewellery—are from Tvedstrand, in the south of Norway.

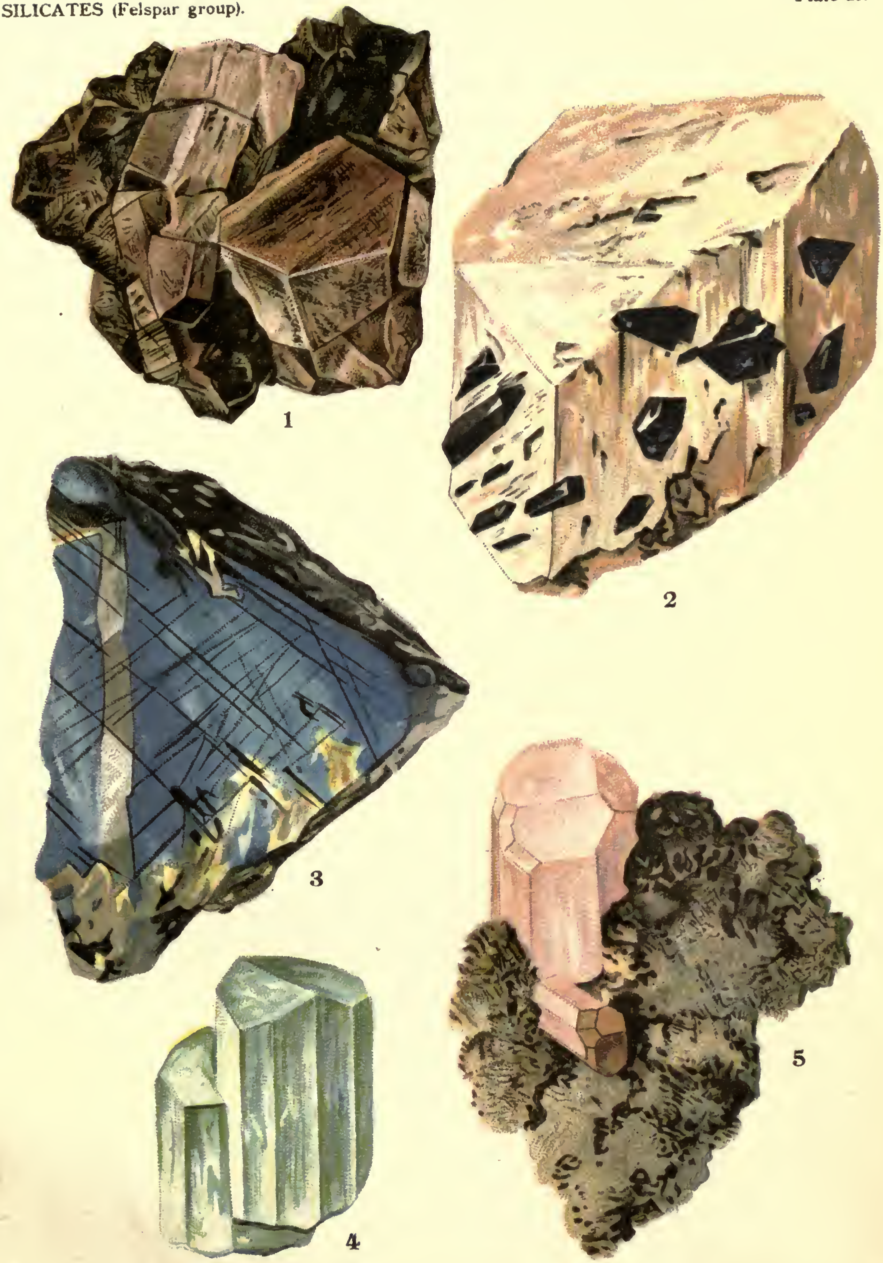
Labradorite (Plate 25, Fig. 3).—Labradorite, or labrador-spar, is another intermediate member of the plagioclase group of felspars, and consists of a mixture of one part of albite with three to six parts of anorthite. It is an important constituent of the more basic igneous rocks, such as basalt and gabbro. In these rocks it is present as smaller or larger embedded crystalline grains; crystals bounded by faces being almost unknown. On the coast of Labrador it forms, with hypersthene (Plate 27, Fig. 5), a rock called norite, which is here so very coarsely grained that the massive pieces of labradorite measure as much as a foot across. In this region pebbles and boulders of labradorite are widely scattered over the surface, the material having been dislodged from the solid rock by the action of ice. These stones are of a dull, greyish-black colour and opaque; but when a wet pebble is held in the hand and turned slowly round, at a certain position, it suddenly flashes with a brilliantly coloured metallic reflection. The colour is an intense red, yellow, green, or blue, resembling the brilliant metallic colours of a peacock's feather or the wings of some tropical butterflies. When the stone is turned away from this position, however slightly, the colour totally disappears. This curious and pretty effect must have been noticed long ago by the Esquimaux; but it was not until 1775 that specimens reached Europe, when they were brought by the Moravian missionaries.

The brilliancy of the reflection is much increased when the stone is cut with a flat surface and polished; but even then it is only in one definite position of the stone relative to the eye of the observer that the colour is seen.

These coloured reflections of labradorite are due to the enclosure in the felspar substance of vast numbers of microscopic plates of other minerals all arranged parallel to a certain crystallographic direction. The substance itself is not coloured, and the colours are produced by the splitting

SILICATES (Felspar group).

Plate 25.



1, 2, Orthoclase. 3, Labradorite. 4, Microcline. 5, Anorthite.

up and reflection of a portion of the white light when its rays strike the parallel series of minute plates at a particular inclination.

This special optical effect is thus quite an accidental character of labradorite, and it is, in fact, shown only by the labradorite from certain localities, more particularly from Labrador (Fig. 3), and less vividly in some specimens from Russia. Labradorite is a common constituent of certain igneous rocks in the British Isles; but none of this material displays the beautiful interference-colours.

Anorthite (Plate 25, Fig. 5).—Anorthite, or lime-felspar, finds its place at the other end of the plagioclase series. The name refers to the fact that none of the angles on the crystals are right angles, the crystals belonging to the triclinic or anorthic system. It is an important constituent of some of the more basic rocks of igneous origin, such as basalt and gabbro, and it has also been detected in some meteoric stones. In igneous rocks it is present only as dull, irregular grains or imperfect crystals. Beautifully clear and glassy crystals, with a profusion of small, brilliant faces, are, however, found in ejected blocks of metamorphic limestone amongst the lavas of Monte Somma, the ancient portion of Mount Vesuvius. These blocks had been ejected long before the sudden and disastrous eruption of 79 A.D. which built up the present cone. Good but opaque crystals, of a pinkish colour, are also found in a metamorphic limestone on the Pesmeda-Alp in Fleims valley, in southern Tyrol; a very fine crystal from this locality is represented in Fig. 5.

The Amphibole Group.

This is another group of isomorphous minerals, which are of importance as constituents of silicate rocks, both those of igneous and of metamorphic origin. Their chemical composition, though varying between wide limits, can always be expressed by the general formula $R''SiO_3$—that is, as salts of meta-silicic acid (see p. 142). In this formula, R″ usually represents calcium, magnesium, and ferrous iron, but sometimes manganese may be present, or aluminium or ferric iron in conjunction with sodium. The actual formulæ may thus be extremely complex.

All the members of the group (with a few exceptions, which need not be mentioned in this book) crystallise in the monoclinic system, and the crystals are usually prismatic in habit. This prismatic habit is often so pronounced that the crystals have the form of fine fibres, needles, or even hairs. Of importance is the presence of two perfect cleavages parallel to the faces of the rhombic prism, the angle of which is about 124°.

Hornblende (Plate 26, Fig. 1).—Common hornblende occurs as an essential constituent of a variety of rocks—for example, granite (hornblende-granite), syenite, diorite; certain volcanic lavas, such as some basalts and andesites; gneisses, schists (hornblende-schist), and metamorphic limestones.

Usually it forms bladed masses embedded in the rock, on the broken surfaces of which the bright prismatic cleavages of the hornblende are conspicuous. In colour it is usually dark green or black, but sometimes brown. The most perfectly developed crystals are those found in limestones which have been baked by close contact with a molten mass of igneous rock. Good crystals are also found, together with other crystallised silicates, in the magnetite-mines of Arendal, in Norway (Fig. 1).

The crystal here represented has the form of a six-sided prism, terminated by three rhomb-shaped faces; and it has very much the appearance of a hexagonal prism with a rhombohedral termination (compare, for example, the rhombohedral crystal of tourmaline shown in Plate 33, Fig. 2).

The six-sided prism is here, however, a combination of the four faces of a rhombic prism, with the angle of 124° (i.e. not very far from 120°), and two faces of the clino-pinacoid parallel to the clino-axis or plane of symmetry (at the sides in the figure). The two rhomb-shaped faces at the top are pyramid faces, and the lower one belongs to an ortho-pinacoid (perpendicular to the plane of symmetry). Such a crystal can be cleaved parallel to the faces of the rhombic prism only, and not parallel to the faces of the clino-pinacoid; whereas if the form were truly hexagonal it could be cleaved equally well parallel to all the prism faces.

Tremolite, or white amphibole, is, chemically, the simplest member of the group, its composition being expressed by the formula $CaMg_3(SiO_3)_4$. It is found as aggregates of bladed crystals embedded in white crystalline limestone, or marble, at Tremola, in Switzerland, and in several other regions where metamorphic rocks occur.

Actinolite (Plate 26, Fig. 2).—Here we have some of the magnesium in the formula just given for tremolite replaced by a small amount of ferrous iron, and it is to this constituent that the mineral owes its characteristic bright green colour. As bladed or needle-like crystals, it is a common constituent of many schistose rocks, and in some cases it makes up the bulk of such rocks. In Fig. 2, representing a specimen from the Zillerthal, Tyrol, dark green blades of actinolite penetrate in all directions a pale green talc-schist. The name actinolite is a Greek form of the old German name Strahlstein, meaning ray-stone, in allusion to the ray-like form of the crystals.

Asbestos is identical, both chemically and crystallographically, with tremolite and actinolite, the whiter varieties, with little or no iron, being near to tremolite. Here the crystals, instead of being bladed or acicular, are thread-like, being enormously elongated prismatic crystals, so fine that they are flexible. The difference is thus merely one of texture. The fibres sometimes grow like hairs from a rock surface, or they may form bundles in the crevices of hornblende-schists and other rocks of metamorphic origin.

This mineral has some curious properties and uses. It may be combed, spun, and woven into cloth, or made into string and lamp-wicks. Being unaffected by fire (the name asbestos means, in Greek, 'unquenchable'), and at the same time a non-conductor of heat, it is used in a variety of forms as a fire-proof and insulating material—for example, theatre curtains, firemen's clothes, linings for iron safes, packing for the pistons of steam-engines, coverings for steam and hot-water pipes and cold-storage plants, &c. Napkins made of asbestos may be cleansed by placing them on a bright fire.

The best qualities of asbestos, with fibres up to six feet in length, come from Lombardy and Piedmont, in the north of Italy. The greater part of the asbestos used commercially is not the amphibole-asbestos here described, but a fibrous variety of the mineral serpentine, known as chrysotile or serpentine-asbestos, to be mentioned farther on. Still another finely fibrous, asbestos-like mineral is the 'blue asbestos,' or crocidolite, to be mentioned presently.

Nephrite (Plate 26, Fig. 4).—This, again, is a variety of amphibole, which, like asbestos, is identical in its essential characters with tremolite and actinolite. The structure is also finely fibrous; but here the fibres are short, and so closely compacted and matted together that they are only recognisable when thin sections of the mineral are examined under the microscope. This peculiarity of structure gives to the stone an extraordinary degree of toughness, so much so that it is extremely difficult to break a pebble or boulder of nephrite by blows from a hammer. The fracture is splintery;

and the hardness, as determined by scratching, is not more than 6 on the scale. Being very compact and fairly hard, the mineral takes a very good polish; and on the polished surface the lustre is somewhat greasy in character. The colour is usually green of various shades, depending on the amount of iron present; but it may sometimes be white if iron is absent.

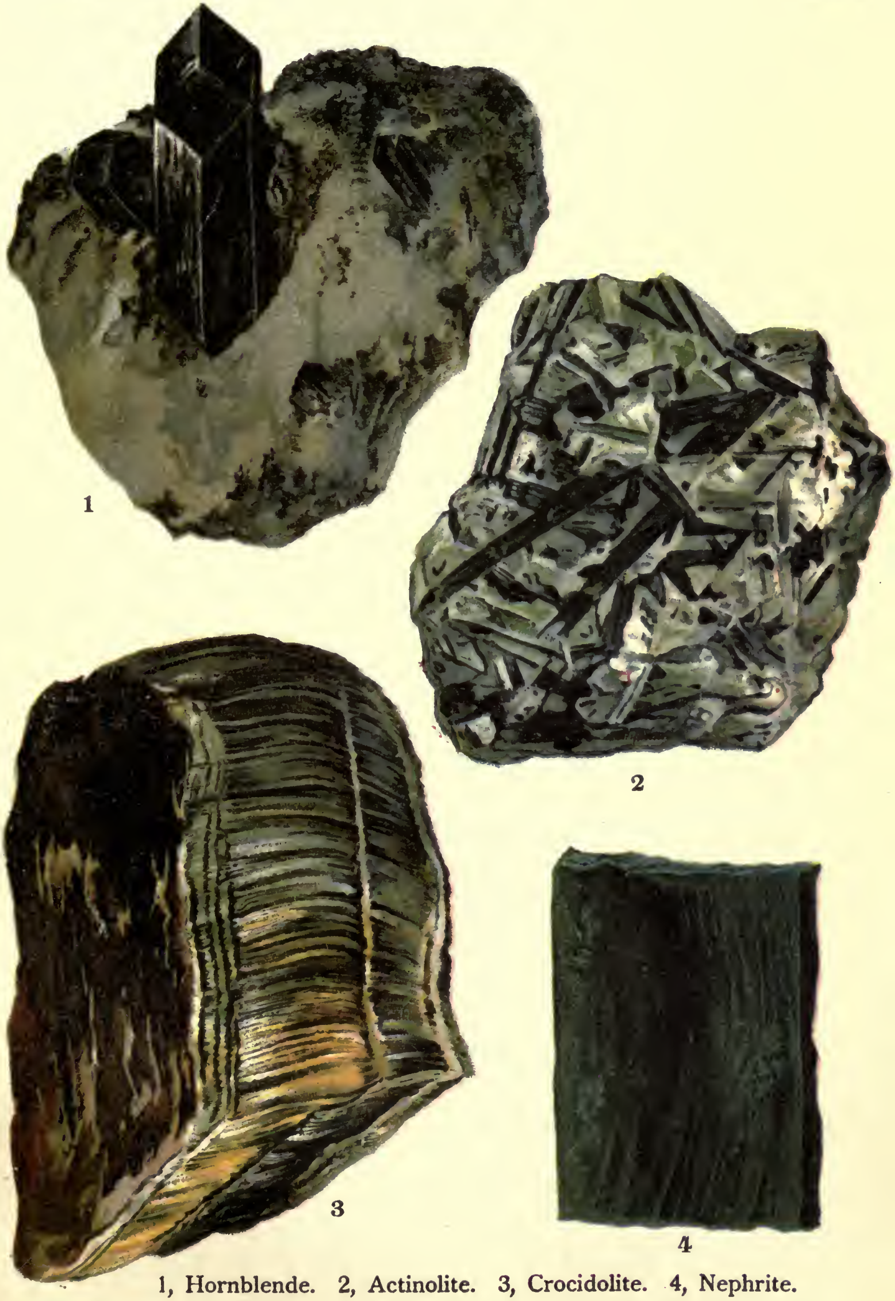
In general character and appearance nephrite is absolutely indistinguishable from the mineral jadeite, a member of the pyroxene group (p. 159). Both these minerals are included under the general term jade, and both are employed for the elaborate carvings so highly prized by the Chinese. They differ widely, however, in their essential characters, notably in their chemical composition, nephrite being a silicate of calcium and magnesium, with often a little iron; whilst jadeite is a silicate of sodium and aluminium. The easiest method of distinguishing the two kinds is by their specific gravity, which may be determined by weighing the carved ornaments in air and in water. The specific gravity of nephrite is 3·0 (or up to 3·1, with darker green varieties), whilst that of jadeite is 3·33. Nephrite, therefore, floats in methylene iodide; whilst jadeite neither sinks nor floats, but remains suspended in the liquid.

Prehistoric celts of nephrite have been found in many parts of Europe, particularly in the ancient lake-dwellings in Switzerland. Axes and other weapons fashioned in nephrite, as well as curious idols, with eyes of inlaid mother-of-pearl, were found in the possession of the Maoris when New Zealand was discovered by Tasman in 1642. In China and India the use of this mineral for carvings dates back many centuries, the nephrite quarries in the Kuen-Lun Mountains having been worked by the Chinese for two thousand years. Several other localities producing nephrite are known in central Asia, but usually the material is found as water-worn pebbles in the beds of rivers and streams. Much of the material now cut in Europe for pendants and other small personal ornaments comes from New Zealand, and is generally known as New Zealand greenstone. This is of a darker shade of green (Fig. 4) than most of the Asiatic nephrite.

The name nephrite is from the Latin *Lapis nephriticus*, or 'kidney-stone,' a name so given because this stone was worn by the ancients as a charm in the belief that it prevented kidney disease.

Crocidolite (Plate 26, Fig. 3).—This is a dark blue, fibrous variety of amphibole, differing considerably in chemical composition from the preceding varieties. It is a silicate of sodium and iron, and has long been familiar through specimens from the Asbestos Mountains, near the Orange River, in South Africa, where it occurs as veins in jasper-schists. The veins are filled from wall to wall by a closely compacted mass of very fine fibres, which, when the stone is rubbed, separate out into a soft, woolly mass. It was this character that suggested the name crocidolite, from the Greek name for wool. The mineral is mined in the Asbestos Mountains, and is put to the same commercial uses as the other kinds of asbestos.

In part of the specimen represented in the picture (Fig. 3) the characteristic blue colour of the mineral gives place to a golden-yellow. This change in colour is the result of a chemical alteration of the mineral, the iron it contains as ferrous silicate being oxidised and hydrated with the formation of limonite. At the same time this alteration is accompanied by the separation of free silica as quartz, which assumes the fibrous structure of the original mineral. We then have a pseudomorph of quartz and limonite after crocidolite; and this is the manner in which the beautiful gem-stone called tiger-eye (p. 90) has had its origin. Unfortunately the name crocidolite is incorrectly applied in the trade to this pseudo-crocidolite.



1, Hornblende. 2, Actinolite. 3, Crocidolite. 4, Nephrite.

THE PYROXENE GROUP.

This is another important group of rock-forming minerals, the members of which are in many respects very like those of the amphibole group (p. 151). They have the same type of chemical formula, $R''SiO_3$, and are also very much of the same type in crystallisation; but with this important difference, that the angle between the prismatic cleavages is here nearly 93°, instead of 124° as in the amphiboles. There are also important differences in the optical characters of the crystals.

This rhombic prism, with angles approximating to right angles, is usually combined with two pinacoids, respectively parallel and perpendicular to the single plane of symmetry; so that we have a nearly regular eight-sided prism (Plate 27, Figs. 1–3), much like the eight-sided tetragonal prism of zircon (shown in Plate 14, Fig. 4). The crystals of the pyroxenes shown in Plate 27 belong, however, to the monoclinic system, with only one plane of symmetry, as may be seen from the pictures. In Fig. 1 this eight-sided prism is terminated by a pair of obliquely placed pyramid planes; and in Fig. 2 there are two such pairs of pyramid planes, together with a small plane at the top of the crystals which is perpendicular to the plane of symmetry. Although these crystals (of augite and diopside) are monoclinic, there are other members (enstatite, bronzite, and hypersthene) of the pyroxene group which belong to the orthorhombic system; but these only rarely occur as distinctly formed crystals.

The name pyroxene has rather a curious history: it means, in Greek, 'a stranger to fire,' and was given in 1796 by the celebrated French mineralogist, the Abbé Haüy, in the belief that the crystals he so named had been accidentally caught up in the volcanic lavas in which they were found. As a matter of fact, as we now know, the pyroxenes are typically minerals of igneous origin, having crystallised out from molten rock-magmas.

Augite (Plate 27, Fig. 1).—This variety of pyroxene is of abundant occurrence as an essential constituent of basalts, gabbros, and other dark-coloured (i.e. basic) rocks of igneous origin. In the lavas of several volcanoes, many of them now extinct, it is found as well-formed crystals embedded in the rock, as shown in Fig. 1, representing a fragment of lava from Bohemia. When the enclosing rock is decomposed and softened by weathering, the crystals of augite fall out, and are often found loose in the soil. These crystals are of a black or very dark green colour, with dull surfaces.

Diopside (Plate 27, Figs. 2 and 3).—This is another monoclinic pyroxene, differing from augite in being less complex in chemical composition. Its formula may be written as $CaMg(SiO_3)_2$, but very often a small amount of ferrous iron takes the place of an equivalent amount of magnesium. As the iron varies in amount in the isomorphous mixture, there is a corresponding variation in the colour of the crystals, from almost white to a dark green, the crystals shown in Figs. 2 and 3 being of an intermediate rich green colour. This variety of pyroxene is usually found as well-formed crystals in limestones which have been subjected to the baking action of molten rock-masses. The lustrous crystals from Ala, in Piedmont, represented in Figs. 2 and 3, are found, together with bright crystals of garnet (hessonite), in veins traversing serpentine. These clear, green crystals are sometimes cut in Turin as gem-stones.

Bronzite (Plate 27, Fig. 4).—The orthorhombic pyroxenes form a series ranging in chemical composition from magnesium meta-silicate ($MgSiO_3$) to iron meta-silicate ($FeSiO_3$), which mix together isomorphously in all proportions. When but little iron is present we have the mineral *enstatite*, which is sometimes found as transparent green crystals, suitable for cutting as gems. Bronzite is an intermediate member of this series, with a composition that may be expressed by the formula $(Mg,Fe)SiO_3$. As represented in the picture (Fig. 4), it occurs as masses composed of a confused aggregate of crystalline individuals, with a fibrous structure, and exhibiting a bronze-yellow colour with a metallic sheen or lustre (hence the name bronzite). These characters are brought out to advantage when the stone is cut and polished, and it is therefore sometimes used for ornamental purposes.

Hypersthene (Plate 27, Fig. 5).—This is another member of the series of orthorhombic pyroxenes, differing from bronzite in containing less magnesium and more iron, so that the formula becomes $(Fe,Mg)SiO_3$. There being here more iron in the mineral, its colour is deeper, being dark brown or brownish-green. In certain specimens the mineral exhibits a very pronounced metallic reflection, and on this account it is cut and polished as an ornamental stone. This character is best shown by specimens from Labrador, where the mineral forms, together with labradorite (p. 150), a coarse-grained igneous rock called norite.

Wollastonite (Plate 27, Fig. 6).—Named after the English chemist and mineralogist, W. H. Wollaston (1766–1828), this mineral of the pyroxene group was earlier known as tabular-spar, on account of the plate-like shape of its rarely occurring crystals. These are white in colour, and consist of calcium meta-silicate, $CaSiO_3$. The mineral is usually found in metamorphic limestones, in which it occasionally forms dendritic growths, as in the black limestone near Pirna, in Saxony (Fig. 6).

There are a few other minerals of the pyroxene group which, although not represented on the plates, are of some importance, and also they supply gem-stones of a fine colour. Of these, *jadeite*, a silicate of sodium and aluminium, has already been mentioned under the mineral nephrite (p. 155), which it so closely resembles in appearance. Another is *spodumene*, a silicate of lithium and aluminium, usually found as ash-grey crystals (hence the name), but sometimes as transparent crystals of a beautiful emerald-green or violet colour; the green variety is known as 'hiddenite,' and the violet, or lilac, as 'kunzite.' A third species is *rhodonite*, a silicate of manganese ($MnSiO_3$), so named because of its characteristic rose-red colour. This is found as small, bright crystals, or as larger masses, suitable for cutting into slabs.

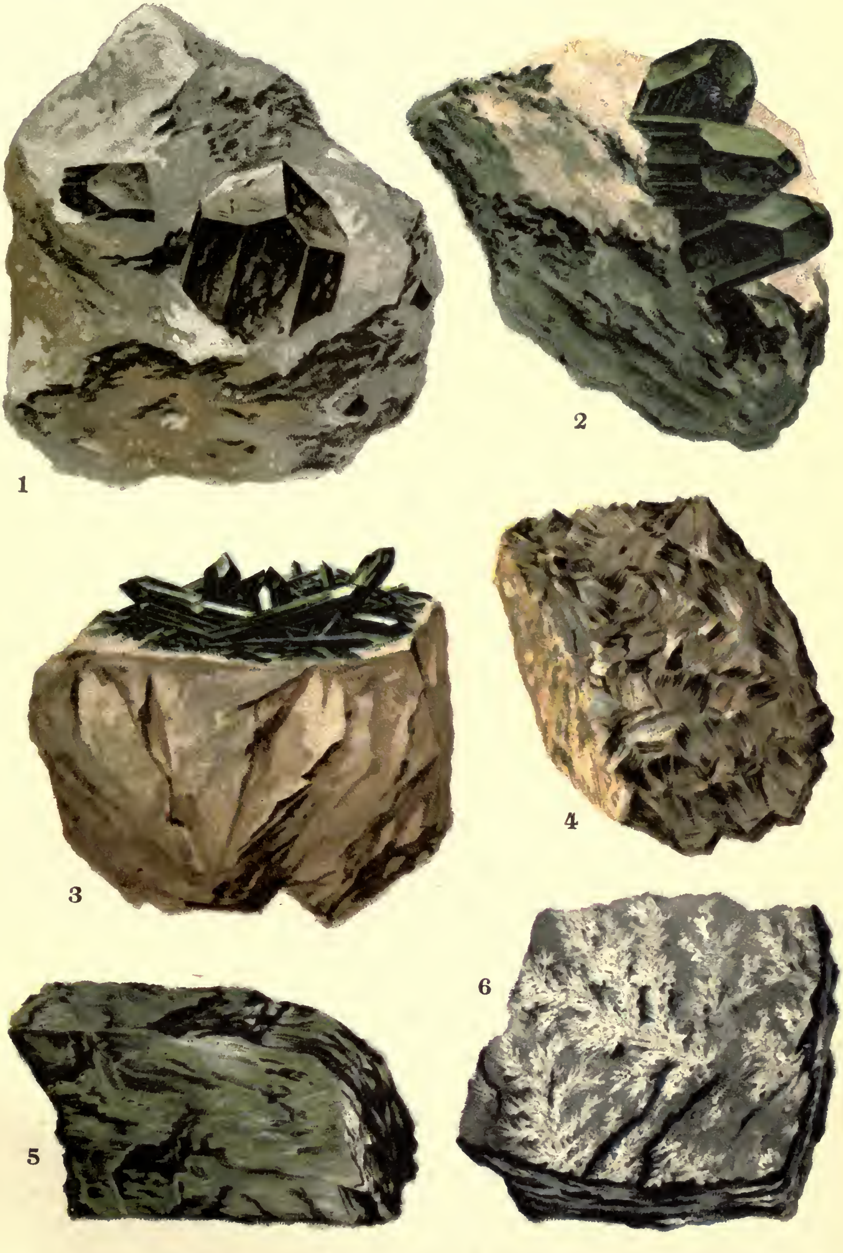
THE SODALITE GROUP.

This group includes a few less common minerals, which are sometimes of importance as constituents of certain kinds of igneous rocks. They are complex in chemical composition, and present the peculiarity of containing chloride, sulphate, or sulphide in combination with the silicate portion. In crystallisation they are all cubic; but distinctly formed crystals are of rare occurrence.

Sodalite (Plate 28, Fig. 1).—This is a silicate and chloride of sodium and aluminium, the name sodalite referring to the presence of sodium, or soda. It is found as clear, glassy crystals in the ejected bombs of Monte Somma, the ancient portion of Vesuvius. The remarkably fine crystals represented in the picture (Fig. 1) are distorted rhombic-dodecahedra, being elongated in the direction of one of the triad axes, and so presenting the appearance of hexagonal prisms terminated by rhombohedral planes.

In another form, of very different appearance, the mineral occurs as compact masses of a bright sky-blue colour (very like Fig. 2 on the same plate). These masses are often of considerable size, and form a constituent of sodalite-syenite at Miask in the Ural Mountains, at Litchfield in Massachusetts, and at Bancroft in Hastings Co., Ontario. At the

SILICATES (Pyroxene group). Plate 27.



1, Augite. 2, 3, Diopside. 4, Bronzite. 5, Hypersthene. 6, Wollastonite.

last-named place the mineral is quarried, and slabs are polished for ornamental purposes. The deposits were being developed at the time of the visit of the Prince and Princess of Wales to Canada, and on account of the interest taken by the Princess (now Queen Mary) in the stone, it came to be known in the trade as 'Princess Blue.'

Lapis-lazuli (Plate 28, Fig. 2).—Another mineral belonging to the sodalite group, and known to mineralogists as lazurite (not to be confused with lazulite, p. 138), resembles sodalite in composition, except that sulphur takes the place of chlorine. This intensely blue mineral enters largely into the composition of lapis-lazuli, which itself is really a fine-grained mixture of minerals, or, in other words, a rock, being of the nature of a crystalline limestone impregnated with lazurite, sodalite, iron-pyrites, &c. On this account, and depending on the amount of lazurite present, the depth of colour shown by lapis-lazuli is somewhat variable, being usually a paler blue in specimens from Lake Baikal (Fig. 2) and Chile, and a richer and deeper blue in the more prized specimens from Badakshan, in central Asia. The stone is spotted and veined with white or yellowish (iron-stained) calcite, and speckled with grains of iron-pyrites. The deep-blue ground set with bright, brassy specks of iron-pyrites suggests a comparison with the blue sky bedecked with stars.

As is well known, lapis-lazuli is much used for small ornaments, such as beads, crosses, &c., and for inlaying in boxes and table-tops. Being an opaque stone, its beauty depends solely on its rich blue colour. When the stone is crushed to powder and the pure blue material is separated by sedimentation in water, the pigment known as ultramarine is obtained. Formerly, when lapis-lazuli was the only source of ultramarine, this was very expensive; but now it is manufactured on a large scale by heating in crucibles a mixture of china-clay (a hydrated silicate of aluminium), sodium carbonate, charcoal, and sulphur.

Leucite (Plate 28, Fig. 3).—Well-formed crystals of this mineral are not uncommon in the lavas of Vesuvius and of the extinct volcanoes near Rome and in the Eifel. They have a rounded appearance, looking like so many angular peas embedded in the rock. They are bounded by twenty-four trapezoidal faces, exactly like the crystals of analcite shown in Plate 36, Fig. 1. This form is the icositetrahedron of the cubic system, the symbol being (112) (see p. 11). Crystals of leucite were long thought to belong to the cubic system; but when they were examined in thin sections under the microscope, it was seen that their internal structure and optical characters did not conform with cubic symmetry. They really consist of a complex lamellar intergrowth of twinned orthorhombic crystals, with the external form of a cubic crystal. When, however, the crystals are heated to a temperature of 714° C., these peculiarities of internal structure disappear, and the crystals are then truly cubic; but on their cooling again the structure reappears. We must, therefore, assume that when the crystals were formed in the red-hot lava they grew as cubic crystals, and that as they cooled the cubic substance became transformed into an orthorhombic substance. We thus have here a peculiar case of dimorphism, analogous to the dimorphism of diamond and graphite (pp. 38 and 49), but one in which the cubic form can only exist at a high temperature; when cooled it changes spontaneously into the second form.

Chemically, leucite is a silicate of aluminium and potassium, with the formula $KAlSi_2O_6$, thus containing the same elements as potash-felspar, but combined in different proportions. It is found, sometimes together with potash-felspar, in certain igneous rocks rich in potash. The name leucite means 'white stone'; but this is scarcely an appropriate name, since the crystals are usually of a dark grey colour, as shown by the specimen from Vesuvius (Fig. 3).

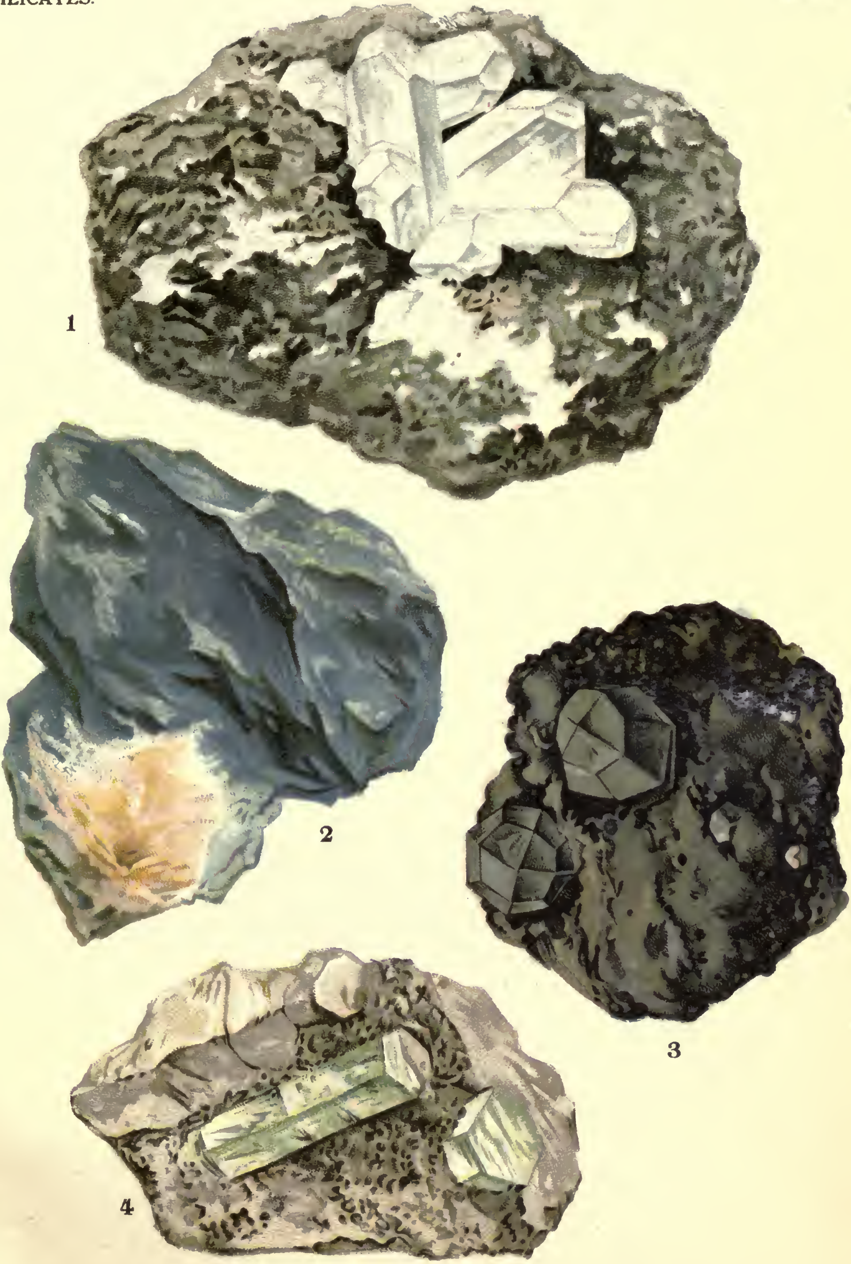
Beryl (Plate 28, Fig. 4).—This mineral is a silicate of the metals beryllium and aluminium, and when quite pure and free from colouring matter and flaws, it is colourless and clear like glass. Such crystals are, however, quite uncommon; more usually they are dull and cloudy and of a pale greenish or yellowish colour, this colour being due to the presence of traces of iron. Sometimes they are transparent and of a rich grass-green colour, and we then have the variety known as *emerald*, which on account of its rarity in clear crystals of a good colour is one of the most valuable of gem-stones. The colour here is probably due to a small amount of chromium oxide. When the colour of the clear crystals is pale yellowish-green, bluish-green, or sea-green, we have the gem-variety known as *aquamarine*. Other crystals are of a yellow colour, approaching golden-yellow. Recently very fine beryls of a rich pink colour have been found in Madagascar and California.

Beryl crystallises in the hexagonal system, usually in very simple forms with only the hexagonal prism and the basal plane (Fig. 4, and Text-Fig. 21, p. 20); but sometimes, especially in the variety aquamarine, there is a rich development of pyramidal faces on the edges and corners between the prism and the basal plane. The habit of the crystals is almost invariably prismatic, and the prism faces are striated in the direction of their length. Enormous crystals, weighing as much as one or two tons, have been found at Grafton and Acworth in New Hampshire, and large crystals are also found in southern Norway. The specific gravity is 2·7, only slightly higher than that of quartz; so that beryl is one of the lightest of gem-stones. The hardness of 7½ is between that of quartz and topaz.

Beryl is of common occurrence in some granites, more particularly in the coarsely crystallised veins of pegmatite which traverse granitic masses. Very good transparent crystals of a blue colour have been found in the granite of the Mourne Mountains in County Down, and opaque crystals in the granite of Counties Dublin and Donegal and in Banffshire. The crystals embedded in white quartz in Fig. 4 are from Bodenmais, in Bavaria. The emerald variety is found in mica-schist in the Ural Mountains, at Habachthal in Salzburg, and at Jebel Zabara in Upper Egypt. At the last-named locality the so-called Cleopatra's emerald-mines were worked in 1650 B.C., and the stones cut as beads and scarabs by the ancient Egyptians. The best emeralds, however, all come from Muzo in Colombia, South America, where they occur, with calcite and black limestone, in crevices in clay-slate. Many of the crystals are much fissured, and stones perfectly free from flaws are extremely rare. The majority of the emeralds so much admired by Indian princes are doubtless of South American origin, and many of them perhaps formed part of the spoil taken from the Peruvians by the Spanish conquerors in the sixteenth century. Aquamarines of gem-quality are mostly from Brazil, the Ural Mountains, and Transbaikalia in Siberia.

THE GARNET GROUP.

The garnets afford an excellent example of an isomorphous group of minerals. They are all alike in their crystalline form, belonging to the cubic system, and they all have the same type of chemical formula. This formula may be expressed generally as an ortho-silicate, $R''_3R'''_2Si_3O_{12}$, where R'' stands for calcium, ferrous iron, magnesium, or



1, Sodalite. 2, Lapis-lazuli. 3, Leucite. 4, Beryl.

manganese; and R‴ stands for aluminium, ferric iron, or chromium. We may thus have the following kinds of garnet, which, it will be seen, vary widely in their actual chemical composition:

Chemical Name.	Chemical Formula.	Mineralogical Name.
Calcium-iron-garnet	$Ca_3Fe_2Si_3O_{12}$.	Andradite.
Calcium-chromium-garnet	$Ca_3Cr_2Si_3O_{12}$.	Uvarovite.
Calcium-aluminium-garnet	$Ca_3Al_2Si_3O_{12}$.	Grossularite.
Iron-aluminium-garnet	$Fe_3Al_2Si_3O_{12}$.	Almandine.
Magnesium-aluminium-garnet	$Mg_3Al_2Si_3O_{12}$.	Pyrope.
Manganese-aluminium-garnet	$Mn_3Al_2Si_3O_{12}$.	Spessartite.

Although these may be taken as the types, it is only rarely that actual crystals correspond exactly with the compounds above stated. What actually happens is that two or more of these compounds help together to build up one and the same crystal, as has already been explained under isomorphism (p. 39). In applying the mineralogical names, we imply that the corresponding chemical type predominates in the particular crystal.

Corresponding with these wide differences in chemical composition, there must of necessity be wide differences in colour (white, black, green, red, yellow, but not blue), specific gravity (3·4–4·3), and mode of occurrence. Amongst them we have gem-stones of red, brown, yellow, and green colours; whilst common garnet is used as an abrasive agent in the form of garnet-paper (sometimes sold under the name of emery-paper). The hardness is about the same as that of quartz, varying from 6½ to 7½. Still another use for garnets is for gravelling garden-walks; the small, rejected material, after picking out stones large enough for cutting as gems, being so used in the garnet-mining district of Bohemia.

Crystals of garnet are always developed to an equal extent in all directions; that is, they present neither a prismatic nor a platy habit, but what may perhaps be described as a granular habit. Most crystals found embedded in rocks have, in fact, the form of rounded grains. It is no doubt on account of this characteristic granular form that the mineral has received its name. The most common crystal form is the rhombic-dodecahedron, which for this reason is sometimes called the garnetohedron. The icositetrahedron, with the symbol (112), as in the crystals of leucite (p. 162) and analcite, is also a common form of garnet crystals. In a combination of these two forms the faces of the icositetrahedron truncate the edges of the rhombic-dodecahedron, as represented in Plate 29, Figs. 1 and 2.

Hessonite (Plate 29, Fig. 1), or cinnamon-stone, is essentially a calcium-aluminium-garnet; but it always contains, in addition, small amounts of ferrous and ferric iron, manganese, and magnesium; so that it is a mixture of five of the garnet substances. The crystals are often transparent, and of a warm reddish-brown, honey-yellow, or hyacinth-red colour, and when cut with facets they afford pretty gems. Beautiful crystals occur, in association with clear, green crystals of diopside, in veins in serpentine at Ala, in Piedmont. The crystals on limestone shown in Fig. 1 are from Sweden. Material of the best gem-quality is found as water-worn pebbles in the gem-gravels of the cinnamon island of Ceylon; the name cinnamon-stone is, however, in allusion to the cinnamon-colour of the mineral.

Almandine (Plate 29, Fig. 2) is essentially the iron-aluminium-garnet, but, like all the garnets, it contains variable amounts of the other types in its mixed crystals. Its colour is a deep rich red, often with a tinge of violet. This garnet is usually cut and polished in rounded convex forms (*en cabochon*), when it often passes under the name 'carbuncle.' Such stones are cut in large numbers at Jaipur, in India, and these Indian-cut gems have much the appearance of jujubes. Almandine is found at many localities, occurring usually in mica-schists and gneisses. The fine crystal embedded in mica-schist shown in Fig. 2 is from Fort Wrangell, in Alaska.

Pyrope, or magnesium-aluminium-garnet, is one of the best-known varieties, and the one most extensively cut as a gem-stone. It is of a fiery-red colour, and passes under a variety of names, according to the locality at which it is found. The best known of these is 'Bohemian garnet,' from the district in northern Bohemia, where an important garnet mining and cutting industry has been established for several centuries. 'Cape ruby' is only another name for pyrope from the diamond-mines of South Africa. 'Elie ruby' is a pyrope from Elie, in Fifeshire, and 'Arizona ruby' from Arizona. Intermediate, in chemical composition, between pyrope and almandine is the beautiful gem-stone called rhodolite from North Carolina, the colour of which is a peculiar and delicate rhododendron-pink.

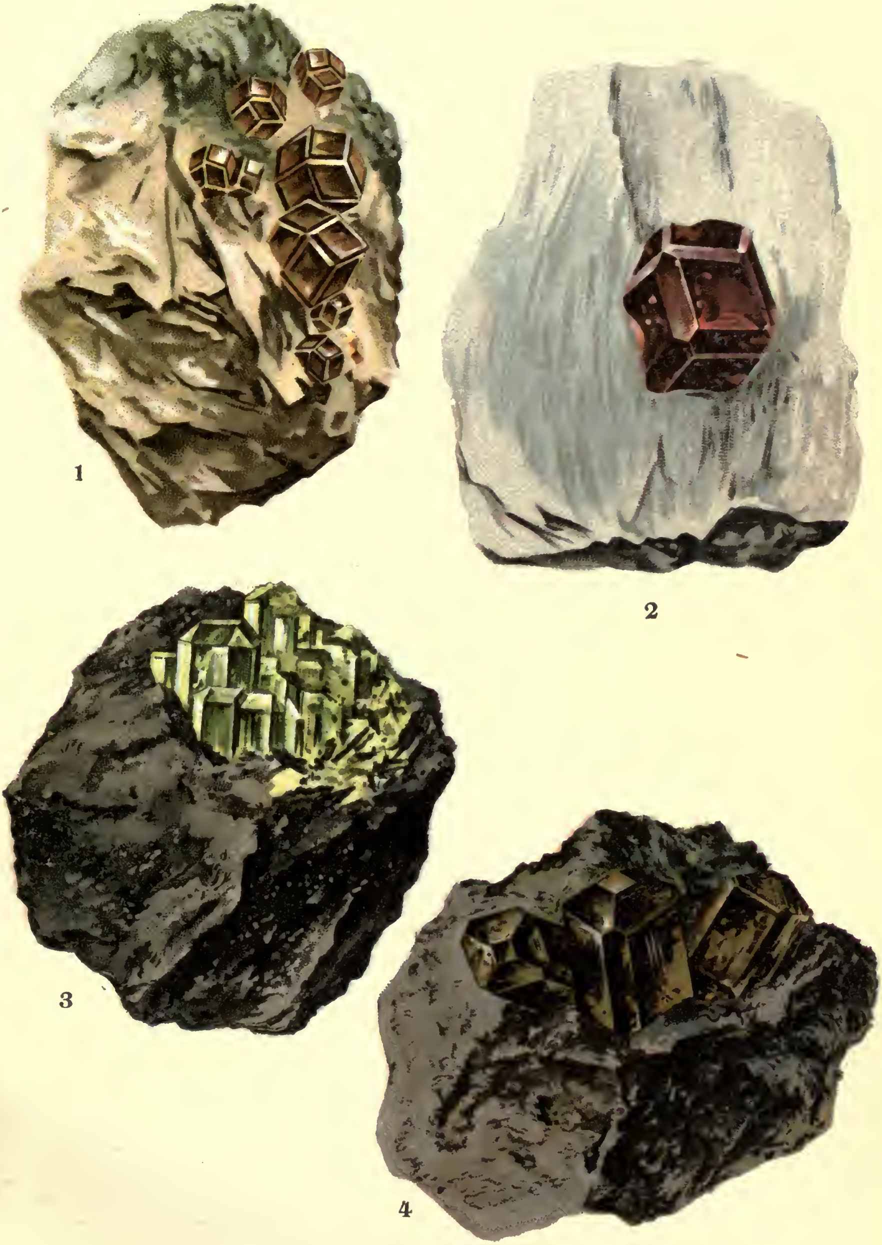
Andradite, the common calcium-iron-garnet, is usually of a dark-brown or black colour; but certain specimens are yellowish-green or emerald-green, and perfectly transparent. The latter occur as rounded nodules in the serpentine-rocks of the Urals, or as pebbles in the neighbouring gold-washings. They cut into very effective and brilliant gems, and go under the names of demantoid, or 'Uralian emerald'; but in the trade they are often erroneously called 'olivine.' Being softer (H. = 6½) than the other varieties of garnet, they, however, do not wear well when mounted in rings.

Grossularite.—When chemically pure, calcium-aluminium-garnet is colourless; but the small water-clear crystals are quite exceptional. Usually the crystals are of a greenish-yellow colour—hence the name grossularite, which, in Latin, means 'gooseberry-stone.' Beautiful rose-pink crystals are found embedded in a white marble at Xalostoc, in Mexico; and with its splashes of pale-green epidote, this garnet-bearing rock has quite a pretty effect when cut into slabs and polished.

Uvarovite, or calcium-chromium-garnet, is of rare occurrence as small, brilliant crystals of a bright emerald-green colour. These are, however, too small, and wanting in transparency, for cutting as gems. This variety of garnet occurs in association with deposits of chrome-iron-ore.

Olivine (Plate 29, Fig. 3).—This is a member of another isomorphous group of minerals, in which magnesium and iron replace each other in the ortho-silicate formula R''_2SiO_4. The pure magnesium ortho-silicate, Mg_2SiO_4, is known as forsterite, and the pure iron ortho-silicate, Fe_2SiO_4, as fayalite, the intermediate members of the series with variable proportions of magnesium and iron being known as olivine. We thus have here a similar case to that shown by the magnesium and iron meta-silicates in the group of orthorhombic pyroxenes (p. 158). With the entry of some other metals, the olivine group may also extend in other directions, and several other minerals of this group are known.

In the gem-varieties of olivine, and also in most rock-forming olivines, the amount of magnesium is largely in excess of the iron; and the colour of such varieties is yellowish-green or olive-green. When more iron, and less magnesium, is present the colour may be brown. Crystals are of rare occurrence, the mineral being usually present as irregular grains or granular masses embedded in certain rocks, of which it forms an important constituent. These rocks are dark basic rocks of the basalt, gabbro, and peridotite families. Some of the peridotites are composed almost entirely of olivine—for instance, the rock called dunite, from the Dun Mountain in New Zealand. Such rocks are very



1, 2, Garnet. 3, Olivine. 4, Idocrase.

liable to alteration when exposed to weathering processes; and by the absorption of water the magnesium silicate passes into the hydrated magnesium silicate serpentine. It is in this way that the large rock-masses of serpentine have originated. An interesting occurrence of olivine is as a constituent of meteoric stones, and as grains in some meteoric irons.

The bright crystals shown in Fig. 3, in parallel grouping, in the cavity of a dark volcanic rock are from Monte Somma, Vesuvius; but such perfect crystals are quite exceptional. They are bounded by three pairs of pinacoids at right angles to one another, three rhombic prisms, and a rhombic pyramid (the small triangular faces on the corners).

Precious olivine—that is, clear, transparent material suitable for jewellery—is also known by the names peridot and chrysolite. Its specific gravity is 3·3; and the hardness being only 6¾, the stone is rather liable to get scratched when worn in rings. Practically all the material of gem-quality comes from the small island of St John in the Red Sea, where it is found as crystals in cavities in an altered dunite. The gem-mining here is a monopoly of the Khedive of Egypt, and is jealously guarded. This material contains a small amount of nickel, to which possibly the rich leaf-green colour is partly due. Gem-material is also found in Arizona and New Mexico.

Idocrase (Plate 29, Fig. 4).—Although this mineral is very simple in its crystalline form, it is extremely complex in its chemical composition. It is essentially a silicate of calcium and aluminium, but many other elements are also present. Crystals are common, and are usually well developed. Those represented in Fig. 4 consist of a combination of two square (tetragonal) prisms, a tetragonal pyramid, and the small, square basal plane at the top. The brown crystals here depicted are from Monte Somma, Vesuvius, where they occur plentifully in the ejected blocks of the old volcano. From this well-known occurrence the mineral is often known as vesuvianite. Crystals of a bright-green colour are found at Ala, in Piedmont, and these are occasionally cut as gems at Turin. At other localities the mineral is usually found in metamorphic limestones. Large blocks of massive idocrase of a rich green colour and with a marked degree of translucency have recently been found in California, this material being cut and polished for a variety of small ornaments under the name of 'californite.'

Topaz (Plate 30, Figs. 1 and 2).—This well-known gemstone presents a wide range of colours. Frequently it is perfectly colourless and water-clear, and pebbles of such material are known to the Brazilians as 'pingos d'agoa' (drops of water). The popular idea of topaz is, however, a stone of a sherry-yellow colour, this being the common Brazilian topaz formerly much used in jewellery; but when this stone is heated it changes in colour to a rose-pink, being then known as 'burnt' topaz. Other stones, which also may be from Brazil, are of delicate blue, bluish-green, or smoke-brown colours.

Topaz is a fluo-silicate of aluminium with the chemical formula $(AlF)_2SiO_4$; but the fluorine is often partly replaced by the elements of water in the form of hydroxyl (OH). The mineral is usually met with as well-formed crystals, but sometimes it is found as water-worn crystals and pebbles. These are orthorhombic, with a prismatic habit, and the prism faces are striated in the direction of their length. The prism invariably consists of a combination of two vertical rhombic prisms, terminated by horizontal prisms or domes, pyramids, and frequently also by the basal plane. The two crystals in Fig. 2 are each bounded by the two vertical prisms, two horizontal prisms, two pyramids, and the base. In Fig. 1 the regularity of the crystal is somewhat interrupted by parallel grouping; but the forms here are the same as before, except that only one horizontal prism (the large triangular face to the front) is present; on the left are four faces of two pyramids, but on the right the two faces of only one pyramid.

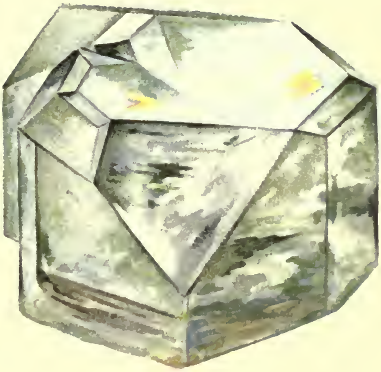
A very important character of crystals of topaz is the perfect cleavage in one direction parallel to the basal plane. The crystals are usually grown attached at one end to the matrix, as in Fig. 2, and when they are detached from this they break away with a smooth plane surface along the cleavage; this is shown by the even underside of the detached crystal in Fig. 1.

The specific gravity of topaz is about the same as that of diamond—namely, 3·5; but the hardness (H. = 8) and brilliancy of lustre are much lower. The crystals are often perfectly transparent, with bright faces; but large crystals are frequently opaque and dull. For instance, a Norwegian crystal, two feet in length and weighing 137 lb., shown in the mineral gallery of the British Museum, is quite opaque and rough. Another noteworthy specimen to be seen in the same collection of minerals is a water-worn pebble of clear, colourless topaz, weighing very nearly 13 lb. Years ago this block had been used as a door-step at a shop in Fleet Street in London. By the man in the street it would no doubt be regarded as a lump of glass and not worth carrying away; but the critical eye of a mineralogist noticed that on two opposite sides of the block there are plane and smooth surfaces of fracture, these being, of course, due to the perfect basal cleavage so characteristic of topaz.

Topaz occurs in nature in veins of tin-ore (cassiterite), and under these conditions small colourless crystals are found in some of the Cornish tin-mines, and in the stream-tin deposits of New South Wales and Japan. The larger crystals occur in crystal-lined cavities in granites and pegmatites. That shown in Fig. 1 is from the granitic rocks at Alabashka, near Ekaterinburg, in the Ural Mountains. Other well-known Russian occurrences are in the Ilmen Mountains and the Sanarka River (here as red crystals in the gold-washings) in the southern Urals, and in Transbaikalia in Siberia. One of the localities in Transbaikalia rejoices in the name of the Borshchovochnoi Mountains, and some very fine crystals from there are preserved in the British Museum collection; but, as they lose their delicate brown colour on exposure to light, they are kept under cover. The crystals shown in Fig. 2 are from the Thomas Range in Utah, where they occur in cavities in a volcanic rock called rhyolite. Much of the gem-material of various colours comes from Minas Geraes, in Brazil.

Andalusite (Plate 31, Figs. 1–3).—This is a silicate of aluminium, Al_2SiO_5, consisting of a combination of one molecule of alumina (Al_2O_3) with one of silica (SiO_2). It is, however, not the only mineral with this chemical composition; there are two others—namely, kyanite (Fig. 4) and sillimanite. These three mineral species are thus trimorphous forms of the same chemical compound, differing from one another in crystalline form and physical characters.

Andalusite forms simple rhombic prisms, with an angle not far from 90°, which are terminated at right angles to their length by the basal pinacoid (Fig. 3); they belong to the orthorhombic system. Usually the crystals are opaque and of a dull grey colour; and they are often coated on their surface with a film of mica (Fig. 3), which has resulted from their alteration. The crystals shown in Fig. 3 are embedded in a vein of white quartz traversing mica-schist, and are from the Lisens-Alp, in the Tyrol. Specimens were first collected at the end of the eighteenth century in Andalusia, and it is from this locality that the mineral takes its name. The same mineral is also found as transparent pebbles in the gem-gravels of Minas Geraes,



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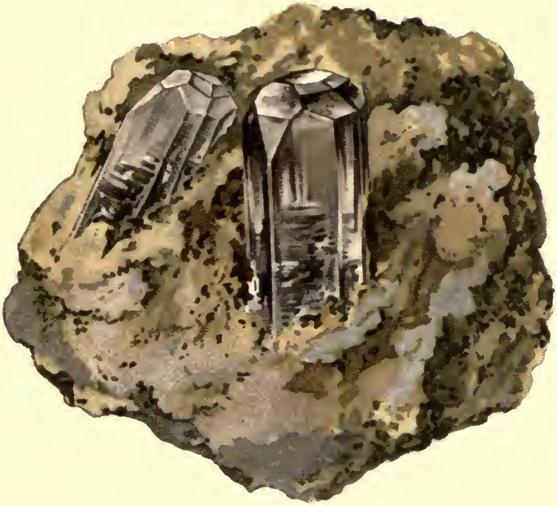


2

1, 2, Topaz.

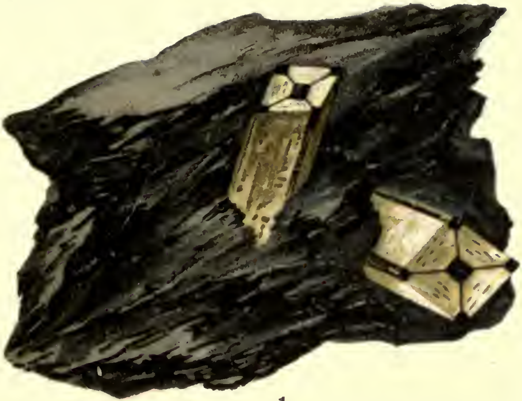
Brazil. These are remarkable for their very strong pleochroism: when looked through in different directions they exhibit different colours—olive-green and blood-red. When faceted as gems, such stones present a very striking effect.

A peculiar variety of andalusite is that known as *chiastolite*, or cross-stone. This contains regularly arranged enclosures of black carbonaceous matter, which has been caught up by the crystals during their growth. When these crystals are cut in slices perpendicularly to the length of the prism, the cross-sections show a pattern, either a black cross on a dirty white or yellowish ground (Fig. 1) or a white cross on a black ground (Fig. 2), depending on the relative amounts of the black enclosures. The crystals represented in the two pictures have been so cut and polished. Polished slices are often mounted and worn as charms. These crystals occur embedded in clay-slates near the contact of these rocks with a mass of granite, and they have been formed by the baking action of the molten igneous mass when it was intruded into the slates. The specimens represented in Figs. 1 and 2 are from Lancaster, in Massachusetts, but similar specimens are found at several other places. Small crystals can be collected in abundance from the slates surrounding the granite of Skiddaw, in Cumberland.

Kyanite (Plate 31, Fig. 4).—Though identical with andalusite in chemical composition, this mineral is quite different in appearance. It occurs as bladed crystals of a sky-blue colour; and it is named kyanite, or cyanite, on account of this characteristic colour. The crystals belong to the anorthic system, but they only rarely show any other form than the very characteristic blades. They have a perfect cleavage parallel to the surface of the blades, and running transversely across this cleavage surface are fine lines due to the presence of secondary twinning (shown at the top in Fig. 4), just as in crystals of stibnite (p. 61). This mineral is of special interest to mineralogists by reason of its peculiarities of hardness. On the bladed cleavage surface in a direction perpendicular to the length the hardness is 7, but in the direction of the length of the crystal it is only 5. This surface can thus be scratched by quartz in one direction, but not in the other.

The bladed crystal in a matrix of white mica-schist represented in Fig. 4 is from Monte Campione, in the St Gotthard district, in Switzerland. Good specimens are also found at Botriphnie, in Banffshire, and at Carrowtrasna, in County Donegal. Clearer material of a deep blue colour is occasionally cut as a gem-stone.

Epidote (Plate 32, Fig. 1).—This is a complex silicate of aluminium, iron, and calcium, with a small proportion of water; but owing to isomorphous mixing the exact composition is somewhat variable. Crystals are monoclinic, with the peculiarity that they are usually elongated in the direction perpendicular to the single plane of symmetry. Only rarely can the forms of the crystals be made out on inspection; they are usually rod-like or needle-like, and arranged in confused or divergent bundles (Fig. 1). They possess a perfect cleavage in one plane direction parallel to their length. One of the most characteristic features of common epidote is its peculiar shade of yellowish-green colour, which is compared to that of the pistachio-nut, and on this account the mineral is sometimes known as pistacite. Sometimes, however, the mineral is brown in colour. Epidote occurs in schists and other metamorphic rocks, and has been formed by the alteration of various minerals, such as felspar, hornblende, &c. A rock composed entirely of epidote and quartz is called an epidote-schist, and it is in the crevices of such rocks that the finest crystals of epidote are found, such as



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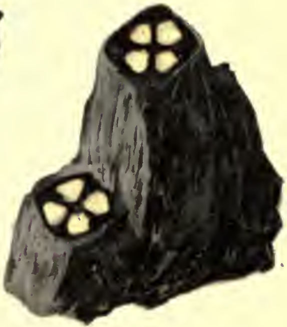

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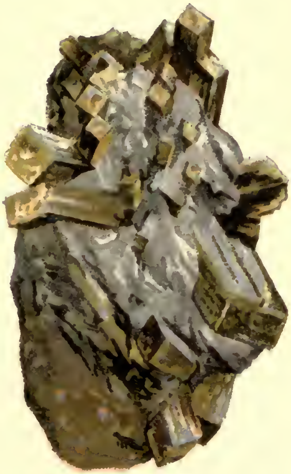

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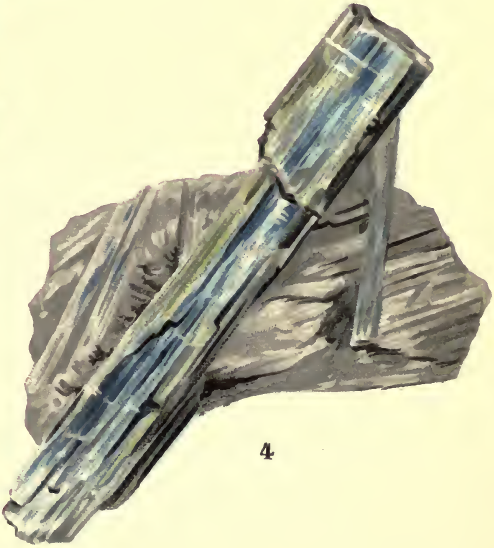


4

1—3, Andalusite (1—2, var. Chiastolite). 4, Kyanite.

those from the Knappenwand, in Untersulzbachthal, Salzburg (Fig. 1). The green crystals from this locality are occasionally cut as gem-stones.

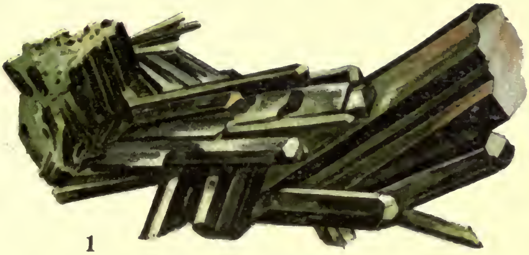
Axinite (Plate 32, Fig. 2).—Axinite takes its name from the characteristic axe-like shape of its anorthic crystals, all the faces of which are obliquely inclined to one another. There being only a centre of symmetry, each simple form on the crystals consists only of a pair of parallel faces; but it will be noticed from the picture that these are arranged in zones around the crystal, with series of parallel edges. The characteristic colour is clove-brown, and the crystals are sometimes glassy and transparent, being then occasionally cut as gem-stones. Chemically, the mineral is a silicate of aluminium, calcium, manganese, and iron, with some boron and a little water. It is of metamorphic origin, and is usually found in crevices in hornblende-schist or in diabase. The best crystals are from Bourg d'Oisans, in dep. Isère, France (Fig. 2); but good specimens are also found at several places in Cornwall.

Prehnite (Plate 32, Fig. 3).—This is a silicate of aluminium and calcium, containing a small proportion of water. It crystallises in the orthorhombic system, but distinctly formed crystals are extremely rare. The individual crystals are closely aggregated in radiating forms, with rounded external surfaces; the botryoidal forms (like a bunch of grapes) shown in Fig. 3 being especially characteristic of the mineral when taken in conjunction with the pale green colour. Prehnite is a mineral of secondary origin, occurring in cavities of basic igneous rocks, such as basalt and diabase, and often in association with the zeolites, with which, indeed, it is sometimes classified. Fine specimens are found in the ancient volcanic rocks at several places in the neighbourhood of Edinburgh and Glasgow, and in those of Paterson, in New Jersey (Fig. 3). The mineral is also found in the Lake

Superior copper-mines, and, together with axinite, at Bourg d'Oisans, in the French Alps. Large masses were long ago met with at Cradock, in Cape Colony, the mineral having been first found there towards the end of the eighteenth century by Colonel Prehn, the governor of the Dutch colony of the Cape of Good Hope, and it was consequently named in honour of him.

Tourmaline (Plate 33, Figs. 1–3).—Owing to isomorphous replacements, this mineral varies so widely in chemical composition that we are really dealing with a group of isomorphous minerals rather than a single mineral. In addition to silicon, aluminium, and boron, it contains smaller and variable amounts of iron, magnesium, lithium, sodium, water, fluorine, &c. It is, therefore, theoretically possible to distinguish as chemical varieties iron-tourmaline, magnesium-tourmaline, and lithium-tourmaline; but such a classification is of little practical value, since these differences in chemical composition are not associated with any marked difference in physical character which would enable us to distinguish readily between one variety and another. To make a chemical analysis of tourmaline involves a long and tedious series of operations; and if only a small gem-stone were available for examination the whole of the material might be used up in arriving at a decision as to its nature. It has, however, long been the custom to distinguish differently coloured gem-varieties of tourmaline by special names: the red as rubellite, blue as indicolite, green as 'Brazilian emerald,' brown as dravite, colourless as achroite, while black tourmaline is commonly known as schorl.

Well-shaped crystals, belonging to the rhombohedral system, are not uncommon, but often the mineral tends to form radiating aggregates of fine needles. An interesting feature of the crystals is their hemimorphic development, the two ends being provided with different crystal-forms. This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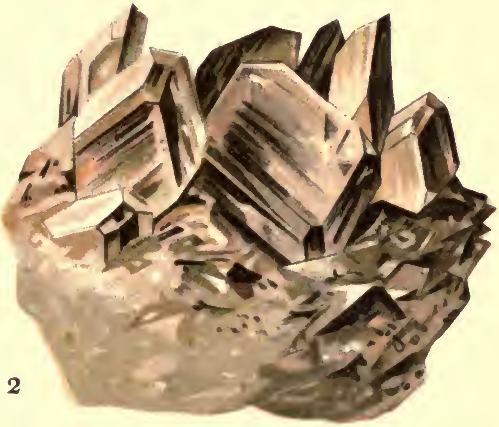
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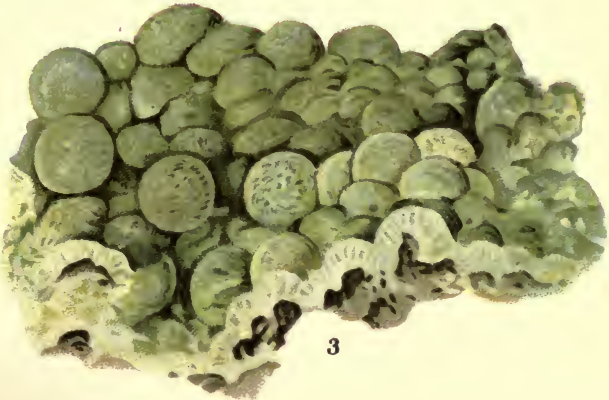
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1, Epidote. 2, Axinite. 3, Prehnite.

is shown by the long prismatic crystal in Fig. 1, there being an obtuse triangular pyramid at the top and a more acute triangular pyramid at the lower end. The shape of the cross-section of the prism is also a very characteristic feature of the mineral. The prism is sometimes simply hexagonal, as shown in Fig. 2, but more often this hexagonal prism is combined with a trigonal (three-faced) prism; in Fig. 1 the long, narrow faces are those of the hexagonal prism, and the wide face seen to the front is one of the three faces of the trigonal prism. Now in most crystals of tourmaline the prism faces are so deeply striated and grooved parallel to their length (an indication of this is seen in Fig. 2) that the nine $(6+3)$ faces round into one another, and we then have a cross-section of the shape of a triangle, with curving convex sides. This character alone is usually sufficient to enable us to identify a mineral as tourmaline.

This hemimorphic or two-ended character of crystals of tourmaline is an outward expression of a peculiarity in the internal structure of the crystalline material, there being a polarity in the arrangement of the crystalline particles building up the crystal. As a consequence of this, crystals of tourmaline behave in a peculiar manner when they are subjected to changes of temperature. If a crystal be warmed it develops a charge of positive electricity at one of its ends, and a charge of negative electricity at the other; while if it be cooled these charges are reversed. The presence of these electrical charges can be demonstrated in a very pretty and conclusive manner by the following simple experiment. A mixture of red-lead and flowers of sulphur is dusted through a fine sieve over a cooling crystal of tourmaline, when it will be seen that one end of the crystal becomes red and the other yellow. The reason of this is that the sulphur is attracted to the positively charged end, and the red-lead to the negatively charged end of the crystal.

This pyro-electric property of tourmaline was first noticed by the Dutch in 1703. Some crystals of the mineral which had been brought from Ceylon had fallen amongst the hot ashes of a peat fire, and it was found that the ashes adhered to the crystals. The mineral was consequently called *aschtrekker*, meaning, in Dutch, 'ash-drawer.' It is interesting to note also that the name tourmaline dates from the same period, being a corruption of the Cingalese word *turamali*.

Another interesting property of tourmaline is one depending on its very strong dichroism. One of the two rays—into which a single ray of light is split on entering the crystal—is almost entirely absorbed, especially in the darker coloured crystals; a plate of tourmaline, cut parallel to the prism edges, may therefore be used for producing plane-polarised light. Two such plates when placed in crossed position over one another almost completely cut out the light; while one by itself or the two placed together in parallel position are transparent. On this depends the use of the little piece of apparatus known as tourmaline-tongs. In some crystals the absorption is so great that a section cut parallel to the basal plane will be quite opaque, while a much thicker section cut parallel to the prism edges may transmit light. The lapidary must take into account this absorptive action of tourmaline, and he must cut a faceted stone in such a direction from the crystal that the large table facet at the front shall be parallel to the direction of the prism edges.

As already mentioned, the colour of tourmaline varies widely; but we may also have a very wide range of colour in one and the same crystal, there often being zones of colour, either perpendicular to (Fig. 2) or parallel to the length of the prism. Some crystals from the island of Elba, of a pale pink colour, are tipped with jet-black, and are consequently described as 'negro-heads.' The lustre of tourmaline is glassy, and the crystals possess no cleavage.

The specific gravity varies from 3·0 to 3·2, and the hardness (H. = 7½) is rather greater than that of quartz.

Tourmaline occurs in granites, mica-schists, gneisses, and crystalline limestones; and mixed with quartz it sometimes forms large rock-masses. It is a constant associate of cassiterite in veins of tin-ore, black tourmaline being a very common mineral in the Cornish tin-mines. Most of the gem-varieties are found as crystals in cavities in pegmatite-veins traversing granite, and they are obtained by quarrying these rocks in California, Madagascar, and the Ural Mountains. The black crystals embedded in white quartz shown in Fig. 1 are from Hörlberg, near Bodenmais, in Bavaria; the crystal in Fig. 2 is from Haddam, in Connecticut; and the radiating groups of pink tourmaline (rubellite), embedded in pale lilac-coloured lepidolite (Fig 3), from Pala, in San Diego Co., California.

Staurolite (Plate 33, Figs. 4 and 5).—Like the name chiastolite (p. 173), the name staurolite also means cross-stone. Here, however, instead of showing a coloured cross inside the crystals, the cross-shaped form is produced by the regular intergrowth of two crystals in twinned position (Fig. 5). The crystals are orthorhombic, and are bounded by a rhombic prism and the basal pinacoid. They are of a dark-brown colour, and usually dull and opaque. Chemically, the mineral is an extremely complex silicate of aluminium, iron, &c. It is found as embedded crystals in mica-schist, as shown in the specimen (Fig. 4) from Brittany. The isolated twinned crystal (Fig. 5) is from Fannin Co., Georgia.

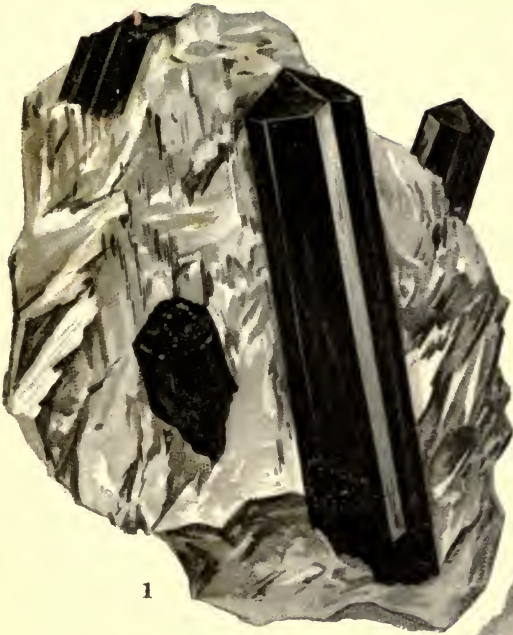
THE MICA GROUP.

The micas are not only of considerable importance as rock-forming minerals, but they also find many useful applications. As essential constituents of igneous and crystalline rocks of many kinds they have an extremely wide distribution.

Granite, for instance, is a rock composed of quartz, felspar, and mica; and mica-schist is a foliated rock, consisting of quartz and mica. When these rocks are broken down by the action of weathering agents, and their materials transported by running water to be deposited in lakes or seas and so form new rocks, the mica, though broken up mechanically into fine scales, resists any chemical actions, and it consequently enters into the composition of the newly formed bedded rocks. If we examine a sandstone with a magnifying lens we shall see on the surface of the bedding planes, along which the stone splits, numerous shining silvery scales of mica. In some sandstones these scales of mica are very conspicuous; while in finer rocks, such as clays, they are very minute.

The micas almost always crystallise as platy or scale-like crystals, and when these have been free to develop at their edges they always have a six-sided outline (Plate 34, Figs. 1 and 3), with angles differing only very slightly from 120°. To all appearances, therefore, the crystals are hexagonal; but exact measurements of the angles between the faces of perfectly developed crystals, and an examination of their optical characters, prove that, in reality, they belong to the monoclinic system.

A very important feature of these crystals is the possession of a perfect cleavage in one plane direction parallel to their large, flat surface. In this direction the crystals can be split up indefinitely into the thinnest of leaves, with perfectly smooth and bright surfaces. At the mica-mines the large crystals are called 'books,' and these are split into leaves in preparing the material for the market. Owing to the presence of this highly perfect cleavage, the flat surfaces of mica display a pronounced pearly or silvery lustre, and also very frequently coloured bands of the same nature as Newton's rings. Being such a very characteristic feature of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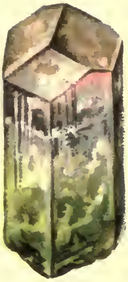
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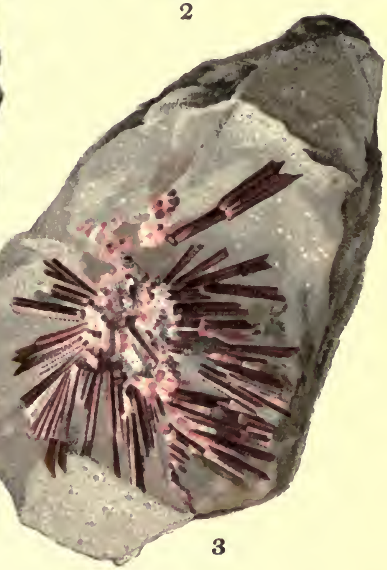
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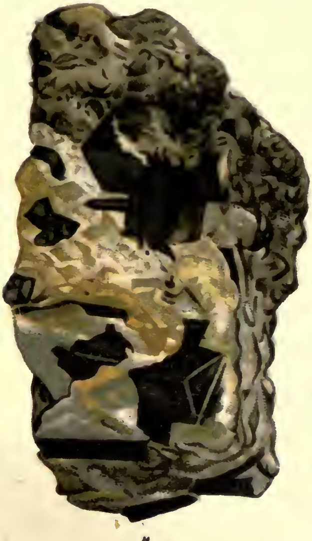
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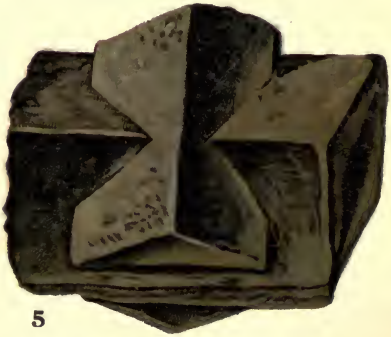
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1—3, Tourmaline. 4, 5, Staurolite.

mica, a cleavage of this high degree of perfection is spoken of as a micaceous cleavage, and as such is very often applied as a descriptive term in connexion with certain other minerals.

The thin cleavage flakes split from a crystal of mica can be readily bent, and when released they spring back to their original position; that is, they are both flexible and elastic. The material is not hard (H. $=2\frac{1}{2}$, about), and the smooth cleavage surfaces can be scratched with the finger-nail, though not so readily as can talc and gypsum. When a sheet of mica is struck a smart blow with a sharp-pointed instrument, a six-rayed star of fracture, called a 'percussion figure,' is produced.

In their chemical composition the micas present a certain analogy to tourmaline; and it is an interesting fact that, under certain conditions in the earth's crust, tourmaline becomes altered to mica. The same chemical elements are present, with the exception of boron. The micas are essentially silicates of aluminium, together with water and alkali metals, and sometimes magnesium, iron, and fluorine. As with tourmaline, so here we may distinguish several chemical varieties—namely, potassium-mica, sodium-mica, lithium-mica, magnesium-mica, and iron-mica. These differences in chemical composition (amongst the micas, much more so than in tourmaline) are accompanied by marked differences in physical characters, especially with respect to the optical properties; and it is thus possible, and also advantageous, to distinguish the different chemical varieties by special names. The most important of these are mentioned below; others are paragonite, or sodium-mica, which occurs as very fine, snow-white scales in certain mica-schists (for example, as the matrix of kyanite in Plate 31, Fig. 4); and lepidomelane, or iron-mica, which is jet-black in colour.

Muscovite (Plate 34, Fig. 1).—This is the potassium-mica; it is the most abundant, and at the same time the chemically simplest, member of the group. Its composition is expressed by the formula $H_2KAl_3(SiO_4)_3$. The hydrogen here plays the part of a metal in the silicate formula; it is expelled as water only when the mineral is heated to a very high temperature.

The larger crystals are usually of a dark greyish shade of colour, but cleavage flakes are often quite colourless and transparent. This transparency of the cleavage sheets has a connexion with the name muscovite, which is merely the mineralogical form of the old and popular name 'Muscovy glass,' clear sheets of this mica having formerly been used instead of glass for windows in Russia. A variety known as fuchsite is bright green, this colour being due to the presence of chromium.

As small scales, muscovite is of abundant occurrence in all countries; but it is only in the pegmatite-veins of certain localities that large crystals and sheets are found. These are mined in India, the United States, and Brazil. The crystal embedded in white quartz shown in Fig. 1 is from the felspar-mines near Kragerö, in southern Norway.

Of the many useful applications to which muscovite—as well as some other kinds of mica—is put, the following may be indicated: for the windows of stoves and lanterns, the peep-holes of furnaces, and the chimneys of incandescent gas-burners. When used for these purposes the material is often popularly called talc; but talc is quite a distinct mineral, to be described presently. Powdered mica is used for producing a spangled effect on toys, stage scenery, wall-paper, &c., and as a lubricant. At the present day, sheets of mica are extensively used in the construction of electrical apparatus and machinery.

Phlogopite, or magnesium-mica, contains the elements magnesium and fluorine in addition to those present in muscovite. It much resembles muscovite in appearance, but is often of a yellowish or brownish shade of colour, and has a more pronounced silvery appearance. It differs also in its mode of occurrence, being usually found in crystalline limestones. The mica extensively mined in Canada and Ceylon is of this variety. It is used for the same purposes as is mucovite.

Biotite (Plate 34, Fig. 2).—This differs from phlogopite in containing some iron in addition to magnesium; it is consequently darker in colour, being deep brown or black. Owing to this colour it is of less commercial value. It is a common constituent of some granites and gneisses. In a kind of granite known as 'two mica' granite, the scales of light-coloured mica are muscovite, and the dark-coloured scales are biotite. Less frequently it is found as large sheets; the cleavage flake of irregular outline shown in Fig. 2 is from Transbaikalia, in Siberia. The mineral takes its name from the celebrated French physicist and astronomer J. B. Biot (1774–1862).

Lepidolite (Plate 34, Fig. 5), or lithium-mica, is of a characteristic lilac or peach-blossom colour. It usually occurs as compact scaly masses, to which the cleavages give a spangled effect. Such material, especially that found near Rozena, in Moravia, is sometimes cut and polished for making small ornamental boxes, &c. Lepidolite invariably occurs in association with pink tourmaline (rubellite), and in Plate 33, Fig. 3, it is shown as the matrix of this mineral. The specimen there represented is from Pala, in San Diego Co., California, where lepidolite is extensively mined. The mineral is used for the extraction of salts of lithium, largely employed in the manufacture of lithia-water.

Zinnwaldite (Plate 34, Fig. 3).—Like lepidolite, this mica also contains lithium and fluorine, but in addition some iron. In appearance it is not unlike biotite. It is found as crystals—never of large size—in veins of tin-ore; the specimen represented in Fig. 3 being from the tin-mines at Zinnwald, in Bohemia, from which locality the mineral takes its name.

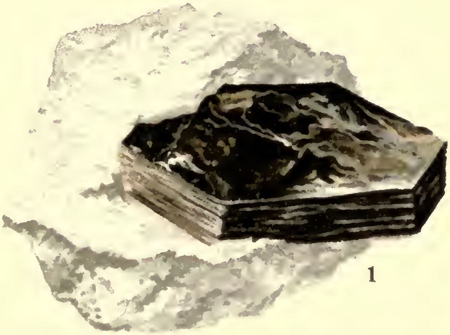
THE CHLORITE GROUP.

The chlorites, or 'hydro-micas,' closely resemble the micas in the form of their scaly crystals and their micaceous cleavage. The cleavage is, however, not quite so perfectly developed, and the cleavage flakes, though flexible, are not elastic. These minerals also differ chemically from the micas in containing more water and no alkali metals. They are characteristically of a green colour, the name chlorite meaning, in Greek, 'green stone.'

These minerals have usually been produced by the alteration of other minerals, such as biotite, pyroxene, &c.; and the green colour frequently shown by altered igneous rocks is due to the presence of chlorites amongst the products of alteration. They also occur in some schistose rocks, and in chlorite-schist (in Plate 38, Fig. 4, as the matrix of perovskite) as an essential constituent. Many varieties are distinguished, but as a rule these are only found as compact masses, with a fine, scaly structure. The only distinctly crystallised varieties are clinochlore and penninite.

Clinochlore (Plate 34, Fig. 4).—This member of the chlorite group is a hydrated silicate of aluminium and magnesium, with variable amounts of iron. It is found as green, platy crystals at West Chester, in Pennsylvania (Fig. 4).

Serpentine (Plate 35, Fig. 1).—The three minerals represented on Plate 35 are all hydrated silicates of magnesium, but, their elements being combined in different



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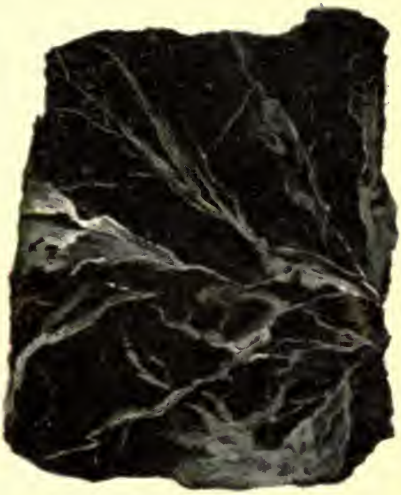

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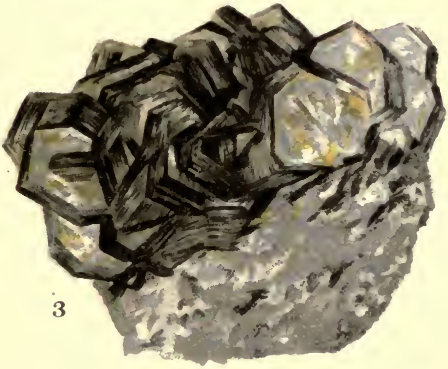

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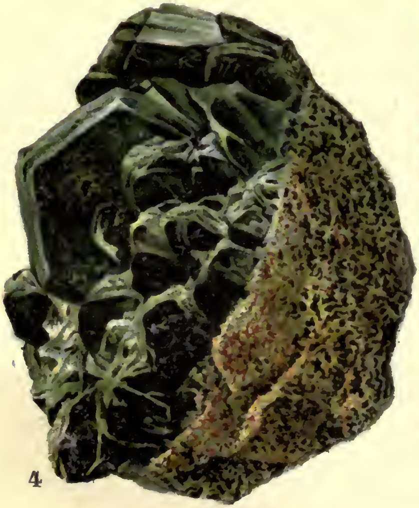

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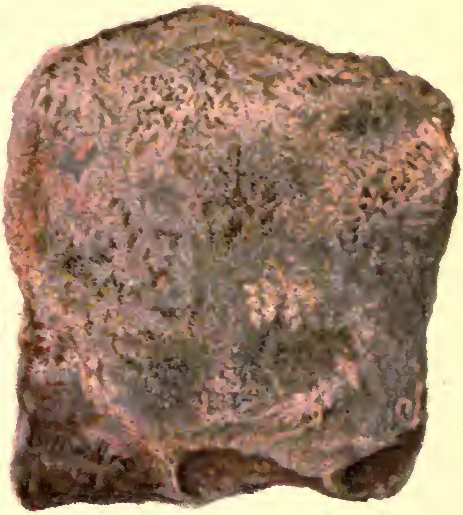

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1, Muscovite. 2, Biotite. 3, Zinnwaldite. 4, Clinochlore. 5, Lepidolite.

proportions, they are quite distinct chemical compounds. Their respective formulæ are:

Serpentine	$H_4Mg_3Si_2O_9$.
Meerschaum	$H_4Mg_2Si_3O_{10}$.
Talc	$H_2Mg_3Si_4O_{12}$.

A small proportion of the magnesium may be replaced by an equivalent amount of iron, this being the case more especially in serpentine, which usually contains 2 or 3 per cent. of ferrous oxide. The water contained in these minerals is expelled only at a red-heat, so that it is present as water of constitution.

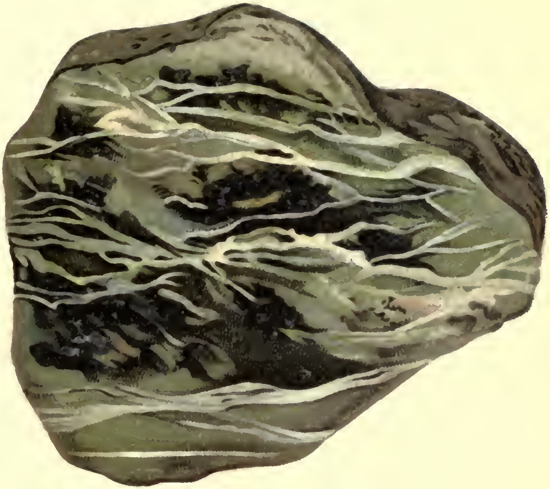
Serpentine never occurs as crystals, but, nevertheless, it varies considerably in its crystalline structure. Usually it is quite massive and compact (Fig. 1), but sometimes it is lamellar or fibrous; the lamellar variety is known as antigorite, and the fibrous as chrysotile. The mineral is usually green, of a lighter or darker shade, but is sometimes yellowish or red. A very characteristic feature is the irregular distribution of the colour, with mottling and veining like that on the skin of a serpent—hence the name serpentine. Specimens of a good colour, and with a certain degree of translucency, are referred to as noble or precious serpentine. Such material, and also the common variety, is extensively cut and polished for ornamental purposes, being frequently used in quite large slabs. In its hardness (H. about 3), and the degree of polish it takes, it resembles marble.

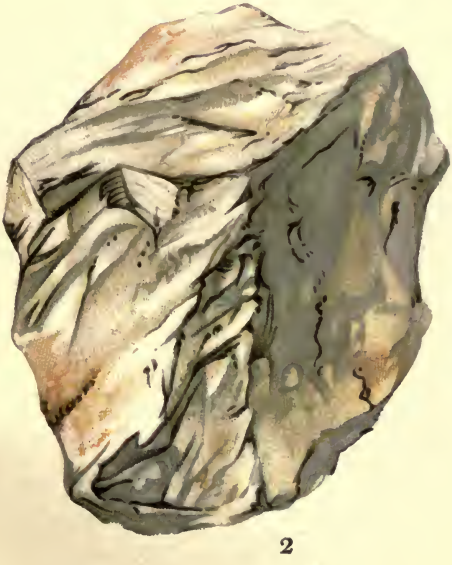
As already mentioned (p. 169), rock-masses of serpentine have originated by the alteration in the earth's crust of rocks composed largely of the mineral olivine. Large masses of serpentine-rock are met with in many districts; for example, it forms the larger part of the Lizard peninsula in Cornwall. Few visitors return from Lizard Town without bringing back some of the small ornamental objects carved in serpentine. The well-known green Connemara marble is a crystalline limestone containing much admixed serpentine. The specimen represented in Fig. 1 is from Reichenstein, in Prussian Silesia.

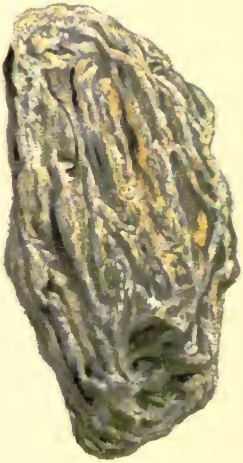
The fibrous variety, chryosotile, occurs as veins in the massive serpentine-rock. The fibres extend from wall to wall of the veins and lie close together. In mass this material presents a very pretty, silky lustre, with a bright yellowish-green colour; but when rubbed between the fingers it separates into white cottony fibres. The veins vary from mere threads to three or four inches across, and they form a network through the whole rock. As already mentioned (p. 154), this material is used for the same purposes as is amphibole-asbestos, and it is extensively mined in Canada. In the trade it is known simply as asbestos, but to avoid confusion it is best referred to as serpentine-asbestos, since the different asbestiform minerals differ so widely in their chemical composition and other essential characters.

Meerschaum (Plate 35, Fig. 2).—The chemical formula of this hydrated silicate of magnesium is given above on p. 185. It is a compact mineral, with a fine earthy texture, and so porous and light that, when dry, it floats on water. The name meerschaum, in fact, means, in German, 'sea-froth.' A mineralogical term sometimes employed is sepiolite, which compares the porous nature of the mineral to that of a cuttle-fish bone. Owing to its porosity, and consequently the avidity with which it absorbs water, the mineral adheres strongly to the tongue, even in quite a painful manner (the waxed and prepared material used for tobacco-pipes does not, of course, do this). The material is quite soft, and can be indented by the finger-nail.

Meerschaum occurs in association with serpentine-rocks; but the material exported in large quantities from Asia Minor is found as small nodules in clayey deposits on the plain of Eski-Shehr, where it is dug from numerous shallow pits. To prepare the material for the market it is scraped







1, Serpentine. 2, Meerschaum. 3, Talc.

free from dirt into curious rounded forms, dried in the air, and the surface waxed. Most of the material is exported through Vienna, and used for the manufacture of tobacco-pipes. Meerschaum of inferior quality forms extensive beds at Vallecas, in Spain, affording a light but valuable building-stone.

Talc (Plate 35, Fig. 3).—The third of these hydrated magnesium silicates (see chemical formula on p. 185) differs from the two preceding in being sometimes crystallised; never, however, as distinct crystals, but only as foliated or lamellar masses. These possess a perfect micaceous cleavage parallel to their surfaces, on which the lustre is silvery and pearly. Such platy and scaly masses have a certain resemblance to mica, but the cleavage flakes are more easily bent, and when released they do not spring back to their original position; that is, they are flexible, but not elastic like mica. Further, the material is greasy or soapy to the touch; and, being the softest of minerals (hardness No. 1 on the scale), it is very easily scratched with the finger-nail. The colour is always of a delicate shade of apple-green with a silvery appearance (Fig. 3).

More frequently, the mineral occurs as compact masses with an earthy fracture, and a white or greyish colour. This variety is known as *steatite*, and also popularly as soap-stone, French-chalk, and pot-stone, the name talc being often restricted to the foliated or micaceous variety. Steatite finds many useful applications. It is used by tailors for marking cloth; for the jets of gas-burners; for furnace-linings, sink-stones, &c. In the powdered form, it enters largely into the composition of toilet-powders, and is employed for preserving rubber, in paper-making, as a dry lubricant, and for adulterating soap. Being soft and easily cut with a knife, it is a favourite material for the grotesque figures carved by the Chinese.

Talc is a very common mineral; it occurs in association with serpentine-rocks, and also as a constituent of some schistose rocks—for example, talc-schist (shown in Plate 26, Fig. 2, as the matrix of the needles of actinolite). Extensive beds of steatite are quarried at several places in the United States, but the best qualities come from the north of Italy.

THE ZEOLITE GROUP.

The several interesting minerals belonging to this group are hydrated silicates of aluminium, with either sodium or calcium, or both of these. They do not form an isomorphous group, as do the minerals of the groups so far considered, for they crystallise in several different systems. Water is present in relatively large amount (10 to 20 per cent.), and as this is only loosely held by the mineral it is regarded as water of crystallisation. When heated before the blowpipe these minerals readily fuse, and the whole mass boils up violently, owing to the rapid expulsion of the water. It is on this account that these minerals receive the name zeolite, which means, in Greek, 'boiling stone.'

The zeolites are minerals of secondary origin, and as such occur in the steam-cavities of certain volcanic rocks, more particularly those of the basalt family. Their light colour, contrasted with the dark colour of the rock in which they are imprisoned, makes them conspicuous objects. The matrix of volcanic rock is shown in all the pictures in Plates 36 and 37. Further, they are, as a rule, beautifully crystallised with brilliant and glassy crystal-faces, and often delicate colouring. Some of the most attractive specimens in collections of minerals are to be seen in the showy groups of crystallised zeolites. Being of abundant occurrence in the volcanic rocks of certain districts, good specimens can be readily obtained by the amateur collector. The best-known localities are in the Middle Lowlands and the Western Isles of Scotland, the north of Ireland, the Faroe Islands, Iceland, and the Midland Mountains in the north of Bohemia; and there are many other important localities.

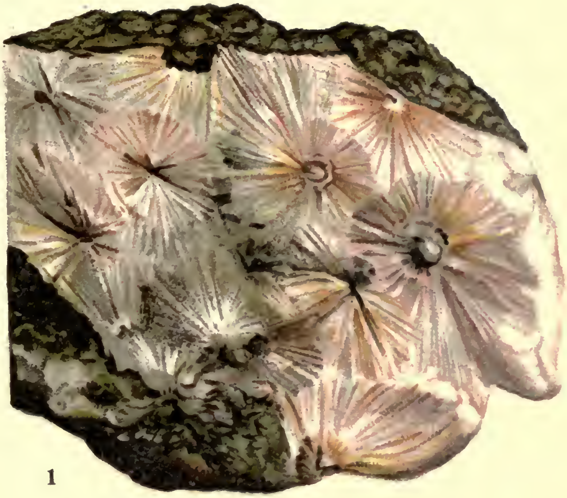
Apart from the point of view of the collector, the zeolites present many points of scientific interest. But as far as economic uses go they are valueless, except that a few massive varieties are used to a very limited extent as second-rate gem-stones. Nevertheless, it would appear that the zeolites play an important part in the economy of nature. In a very minute state of division they have been proved to be present in soils; and it is probable that the soluble forms of the alkalis necessary for the life of plants are here held as constituents of zeolites. The formation of zeolites, resulting from the decomposition of felspar and other mineral particles in the soil, prevents the immediate and total removal of the alkalis in a still more soluble form.

Besides the four species of zeolites figured on the accompanying plates (36 and 37), many others are known to mineralogists. Harmotome is of interest in containing barium, brewsterite contains strontium, and in phillipsite there is potassium. In laumonite the water is held so loosely that it escapes in a dry atmosphere, and the transparent glassy crystals crumble to powder. Apophyllite is remarkable for the size and perfection of its crystals. Prehnite, already described (p. 175), is also sometimes classified with the zeolites.

Analcite (Plate 36, Fig. 1).—This is a hydrated silicate of aluminium and sodium. With one rare exception, it is the only zeolite that crystallises in the cubic system. The most usual form is an icositetrahedron (Fig. 1), with the symbol (112), a twenty-four-faced solid already mentioned under leucite (p. 162). Cubes, with each of their corners replaced by three small triangular faces of the same form, are also met with in analcite. The walls of the rock-cavities are sometimes completely lined with a crust of small, brilliant, and sparkling, water-clear crystals; or, again, a cavity may contain only a few fine, large, and opaque crystals of a white or pinkish colour, as in Fig. 1, representing a specimen from the Fassa valley in the Tyrol.

Chabazite (Plate 36, Fig. 2).—In addition to sodium and aluminium, this zeolite contains some calcium. The crystals are rhombohedral, and the simple rhombohedra are very nearly cubic in their angles. Sometimes, however, the form is that of a flattened rhombohedron, with rounded surfaces, and the crystals are then very like lentil-seeds in shape. Very often the crystals are twinned with interpenetration, the corners of one individual of the twin projecting through the faces of the other (Fig. 2). As with analcite, crystals of chabazite are either colourless and transparent, or opaque and white or pinkish. The specimen figured, showing crystals in a cavity in basalt, is from Nidda, near Giessen, in Hesse.

Natrolite (Plate 37, Figs. 1 and 2).—As its name signifies, this zeolite contains sodium, natrium being the Latin name of this element. The name sodalite (p. 160) has the same meaning. Natrolite differs, however, from sodalite in containing water, but no chlorine, in addition to soda, alumina, and silica; and it differs from analcite in its constituent elements being combined in other proportions. The crystals are orthorhombic, and they often have the form of very delicate needles growing out in thick clusters from the surface of the rock. On this account the mineral was formerly known as needle-stone. Frequently the needle-like crystals or fibres are closely aggregated in compact, radiating groups, as shown in Figs. 1 and 2. The isolated needles are usually perfectly colourless and transparent; while the radiating masses are cloudy or opaque, and of a white,



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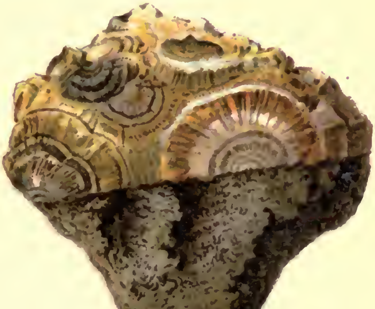

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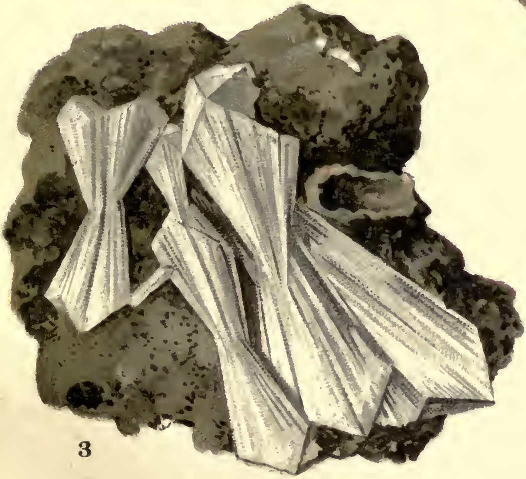


3

1, 2, Natrolite. 3, Stilbite.

pinkish, or yellowish colour. The yellowish radiating natrolite shown in Fig. 2 is from a well-known occurrence at Hohentwiel, in Würtemberg; on account of the pretty, concentric banding of the colour this material is sometimes cut and polished for small ornaments.

Stilbite (Plate 37, Fig. 3).—This contains calcium, not sodium, in addition to aluminia, silica, and water. The crystals are monoclinic, but owing to twinning they are very complex. Sometimes they have the form of elongated six-sided plates; but more often the crystals are grouped in sheaf-like aggregates (Fig. 3, from Iceland), this form being a very characteristic feature of the mineral. The crystals have a perfect cleavage in one direction, and on this surface the lustre is markedly pearly in character. Although the mineral is usually snow-white, crystals from Old Kilpatrick, in Dumbartonshire, are brick-red in colour.

CHAPTER XIII.

The Titano-silicates, Titanates, and Niobates.

The preceding chapter on the silicates is by far the longest in the book; the present one will be the shortest. The rare minerals here grouped together are salts of the metallic acids, titanic acid and niobic acid. Titanic acid is allied, chemically, to silicic acid, and in the mineral sphene both of them are present. On the other hand, niobic acid is related to arsenic and vanadic acids. In a strictly chemical classification, therefore, the titanates should be placed with the silicates, and the niobates with the phosphates and arsenates. But as a matter of convenience, the titano-silicates and titanates may be considered as an appendix to the silicates; and since niobic and titanic acids are often present together in the same minerals, there is some excuse for grouping the niobates with the titanates.

Sphene (Plate 38, Figs. 1 and 2).—Though not an abundant mineral, sphene is by far the commonest of this group, the others being of quite rare occurrence. It is a silicate and titanate of calcium, with the formula $CaTiSiO_5$. Since it contains the element titanium, it is often known as titanite. The name sphene refers to the wedge-shaped form of the monoclinic crystals. Crystals of the size and perfection of those shown in the accompanying pictures are most exceptional. Usually they are quite small, and are found embedded in igneous and crystalline rocks of various kinds—for example, in the granite of Criffel, in Galloway. The best crystals, of a green or greenish-yellow colour and often transparent, are found on the walls of crevices in the gneissic rocks of the Alps (Fig. 1); while the largest, of a dark-brown colour, are met with in crystalline limstones in Canada and the United States, the specimen shown in Fig. 2 being from Diana, in Lewis Co., New York.

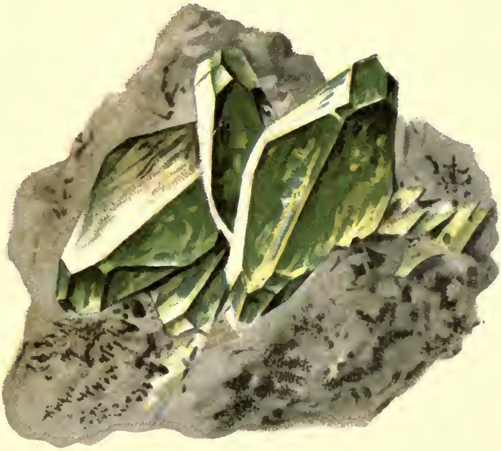
Transparent crystals are occasionally cut as gems. These display pretty green and red flashes of colour; but unfortunately they are rather too soft (H. = 5½) to withstand much wear.

Perovskite (Plate 38, Fig. 4).—This is a titanate of calcium, $CaTiO_3$, with a formula analogous to that of the calcium silicate wollastonite; but there is no further similarity between these two minerals. Perovskite is found as dull or lustrous, dark-brown or black cubes in chlorite-schist at Zermatt, in Switzerland, and at Achmatovsk, in the Ural Mountains. The specimen represented in Fig. 4 is from the latter locality (the white mineral here shown is calcite). The crystals, though presenting the external form of cubes, have a complex internal structure similar to that shown by leucite (p. 162).

Columbite (Plate 38, Fig. 3).—This rare species is a niobate of iron, $FeNb_2O_6$, but the iron is often partly replaced by manganese, and the niobium by tantalum. The metal columbium (later renamed niobium) was discovered in this mineral by the English chemist and mineralogist Charles Hatchett in the year 1802, and was so named by him because the specimen he examined came from America; the mineral itself he called 'ore of columbium,' and very soon afterwards it was given the mineralogical name columbite. The mineral occurs as well-developed orthorhombic crystals in pegmatite-veins. In colour they are dark brown or black, usually with dull faces, but sometimes they are very lustrous. The specimen represented in Fig. 3, with brilliant, black crystals embedded in white quartz, is from Standish, in Maine.

When the amount of tantalum exceeds that of niobium we have the very similar and isomorphous mineral *tanta-*

lite, which is thus essentially a tantalate of iron, $FeTa_2O_6$. Within the last few years this rare mineral has come to be of considerable importance as a source of the heavy metal tantalum, now extensively used for the metallic filaments of incandescent electric lights. Being a metal possessed of great hardness, and other exceptional properties, it will no doubt in the future find many other useful applications.



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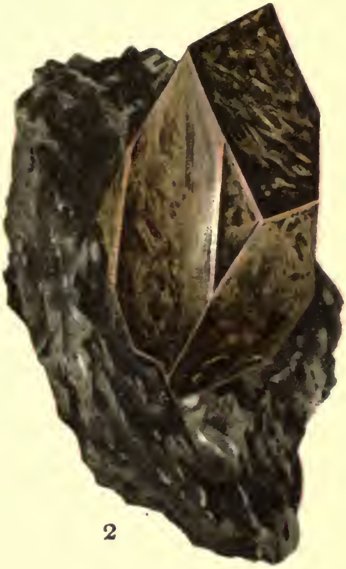

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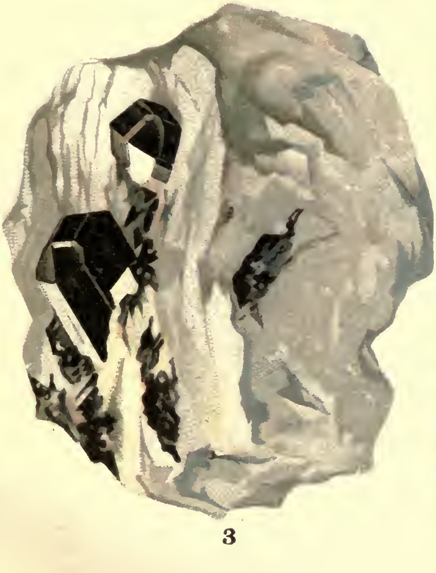

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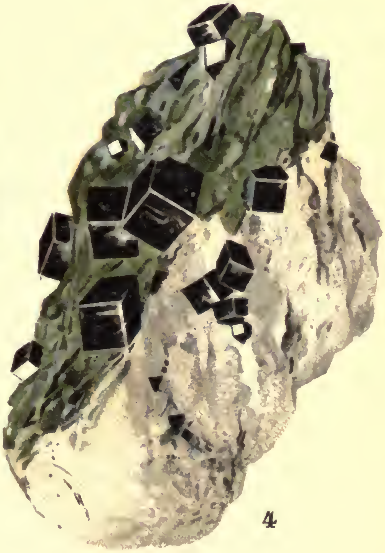


4

1, 2, Sphene. 3, Columbite. 4, Perovskite.

CHAPTER XIV.

The Organic Substances.

The substances to be here considered cannot, strictly speaking, be regarded as mineral species, for, with very few exceptions, they possess neither a crystalline structure nor a definite chemical composition. Many of them are clearly of organic origin, and represent the fossilised remains of plants; but this is not always the case, as will be mentioned under asphaltum. In the systems of classification in mineralogy they are usually relegated to an appendix or omitted altogether. But on account of their great economic importance they cannot be completely neglected.

Chemically, they consist of carbon in combination with hydrogen, or with hydrogen and oxygen, and they are therefore described as hydrocarbons. It is, however, important to remember that some of the minerals we have already described as definite species also contain carbon—for example, the carbonates (Chapter IX.)—while diamond and graphite consist wholly of this element. In addition to these there are also a few other rare minerals, occurring in a crystallised form, which consist of salts of the so-called organic acids—for example, the mineral whewellite, a hydrated oxalate of calcium.

Amber (Plate 39, Fig. 1).—Amber is a fossil resin found as small nodules in certain beds of clay and sand. These nodules, which occasionally have the form of drops or tears, represent the drops of viscous resin exuded from the trees of a species of pine, *Pinites succinifer*, now long since extinct, which in past ages of the earth's history (the Oligocene period of geologists) grew on the site now occupied by the Baltic and the North Sea and a portion of northern Europe. The resin no doubt became buried in the soil, in the same way that we find at the present day the kauri-gum in New Zealand and the copal-resin near Zanzibar. When, however, owing to movements of the earth's crust, these forest areas came to be submerged below sea-level, the surface materials with their contained amber were re-sorted and deposited on the bottom of the sea as beds of sand and clay. Here the resin remained for countless ages, undergoing a slow hardening and change in the nature of its substance.

Much of this history can be made out from a study of the various substances which we find enclosed in amber, such as fragments of wood, pine-needles, leaves, insects of various kinds, and even snails and other small animals, inhabitants of the primeval forest, which got caught in the viscous resin. Fig. 1 of Plate 39 shows an insect enclosed in a cut and polished piece of Baltic amber.

The amber-bearing beds now outcrop in the north of Prussia, and they also form the floor of a portion of the Baltic. When these submarine strata are disturbed by storms, the nodules of amber are washed out and cast up on the beach. Formerly, nearly all the amber collected was picked up off the beach or netted in the shallow water. Later, dredging was resorted to; but at the present time the largest quantities of amber are obtained by a regular system of underground mining in the amber-bearing strata. These strata extend to the east into Russia, and westward into Denmark; while occasionally fragments of amber are picked up on the coasts of Essex, Suffolk, and Norfolk. The richest deposits are, however, those in the north-east of Prussia, in the district of Samland, and practically the whole of the amber trade is centred round Danzig and Königsberg. This amber is therefore known as Prussian or Baltic amber to distinguish it from other less valuable fossil resins of somewhat similar character found in other parts of the world.

As is well known, amber is yellow in colour—indeed, we speak of amber-yellow, but the shade of yellow differs widely in different specimens; it may be very pale, almost white, to a deep reddish-yellow or brown. Also in the degree of transparency there is a wide range; the best pieces are perfectly transparent and clear (as in Fig. 1); while others are cloudy and opaque, these being known as bone or osseous amber. Sometimes there are both clear and cloudy patches or bands in the same piece. The opacity is due to the presence of vast numbers of microscopic air-bubbles in the amber. The specific gravity is 1·05; that is, amber is only slightly heavier than water. Its hardness is 2½ on the mineralogist's scale, being rather greater than that of gypsum and alabaster. Chemically, it consists of carbon, hydrogen, and oxygen in approximately the proportions given by the formula $C_{10}H_{16}O$. As shown by the action of various solvents (turpentine, alcohol, &c.), it really consists of a mixture of resins; and, in addition, it contains an organic acid known as succinic acid, the presence of which is an important character of the true Baltic amber (succinite).

Being a bad conductor of electricity, amber becomes electrified when rubbed on cloth, and it will then attract to itself small bits of paper and other light objects. It is from the Greek name *elektron* for amber that our word electricity is, on this account, derived.

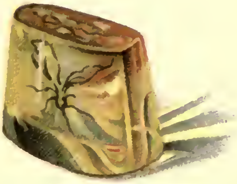
The uses of amber are well known. It is cut and polished as beads and other personal ornaments, and for the mouthpieces of tobacco-pipes, cigar- and cigarette-holders. Small fragments and chips when heated under hydraulic pressure become welded together, and the pressed amber, or ambroid, so obtained is put to the same purposes as the natural pieces.

Asphaltum (Plate 39, Fig. 2).—Asphalt, bitumen, or mineral-pitch is a jet-black substance, breaking with a smooth and bright conchoidal fracture (Fig. 2). It varies, however, considerably in its characters, and is really an indefinite mixture of hydrocarbons, which are in part oxygenated. The specimen represented in the picture is from the famous pitch-lake on the island of Trinidad. This lake, or rather cake, of asphaltum has a circumference of one and a half miles, and a depth of eighteen to seventy-eight feet. It is said that formerly the material was liquid and warm towards the centre, but now it is solid throughout. A viscous bitumen oozes from the ground round the Dead Sea, while in the lake itself there occasionally rise to the surface considerable masses of bituminous matter. As this dries on exposure to the sun it sets as asphaltum. This material was used by the ancients for pitching their boats, and the Greek name Lake Asphaltites, meaning bituminous lake, for the Dead Sea, is the origin of our name asphaltum.

Asphaltum impregnates many rocks of sedimentary origin; but it also sometimes occurs in small amounts in igneous and crystalline rocks and in some mineral-veins. In the latter case the substance can scarcely be of organic origin. In some of the Derbyshire lead-mines there is found a peculiar form of asphaltum known as elaterite, or elastic bitumen, which is soft and elastic like india-rubber.

Lignite (Plate 39, Fig. 3).—This is merely fossil wood, still plainly showing the woody structure (Fig. 3). It has thus little claim to rank as a mineral in our meaning of the term. The degree of the fossilisation may, of course, vary between wide limits, for lignite is only an intermediate stage in the formation of coal. Extensive beds of lignite are found in strata of the more recent (Tertiary) geological periods—for example, at Bovey Tracey, in Devonshire. The specimen represented in the picture is from Germany, in which country lignite, or brown coal, is of considerable importance as a fuel.

In strata of Liassic age near Whitby, in Yorkshire, there is found a still more fossilised variety, approaching coal in



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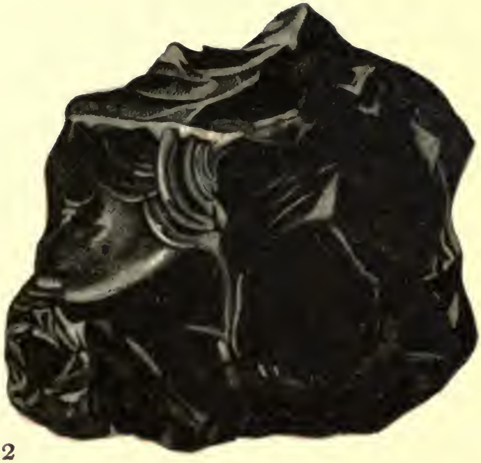

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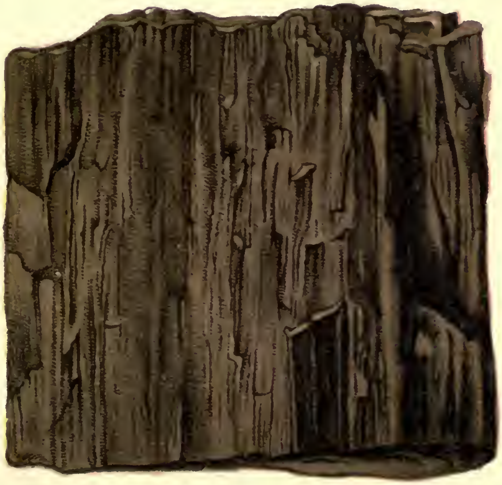

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1, Amber (enclosing insect). 2, Asphaltum. 3, Lignite.

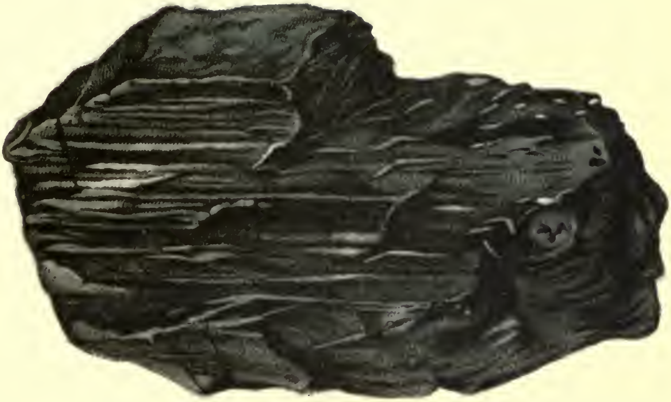
character; this is black and compact, though the exterior form of the masses is that of tree-trunks. This is the material well known as jet, which is extensively cut and polished for a variety of small ornaments.

Coal (Plate 40, Fig. 1).—It would be out of place here to give an adequate account of the characters, occurrence, and origin of this important substance, on which the industrial prosperity of Great Britain so largely depends. It is found as beds or seams, varying in thickness from a fraction of an inch to thirty feet or more, interbedded with sandstones and shales in the rocks of various geological periods, but mainly in those of the period to which the name Carboniferous is appropriately applied. At this remote period of the world's history there were extensive swamps, with luxurious growths of vegetation—vegetation of quite a different character from that of the present day. Thick accumulations of vegetable matter were formed in much the same way that peat forms at the present day; and these became covered by the sedimentation of clay and sand, and so preserved. With a slow and continual sinking of the area, owing to movements of the earth's crust, a great thickness of alternate layers of sand, clay, and vegetable remains was piled up. Under this enormous pressure, and with various chemical reactions in the presence of water, acting for millions of years, the sands have become converted into sandstones, the clays into shales, and the vegetable remains into coal. Trunks and roots of fossil trees are frequently found in the rocks of the coal-measures; but in the coal itself the material has been so altered by fossilisation that little organised structure remains, and, as a rule, can only be detected when thin sections of the material are examined under the microscope.

The reader will no doubt have noticed that some kinds of coal break into small cube-like blocks, with smooth and bright surfaces. This fracture is a result of jointing in the material, and is altogether distinct from the cleavage of crystals, since, although the blocks are sometimes quite small, the subdivision cannot be repeated indefinitely.

Often, also, it may be noticed that such surfaces have a thin, brassy coating, looking like gold. This is the mineral iron-pyrites (p. 72), which is also sometimes present as small nodules embedded in the coal. A piece of coal containing these nodules detonates and flies about when placed in the fire.

Anthracite (Plate 40, Fig. 2).—This is a variety of coal in which the process of fossilisation has proceeded still further, and no trace of organised structure remains. The volatile material is much reduced in amount, and the material consists largely (up to 95 per cent.) of pure carbon. Anthracite is brittle, and breaks with a smooth and bright conchoidal fracture very like pitch, as may be seen from a comparison of the two pictures on Plates 39 and 40. The surfaces of anthracite sometimes display a brilliant iridescent tarnish. The chief sources of supply are the coal-fields of South Wales and Pennsylvania.



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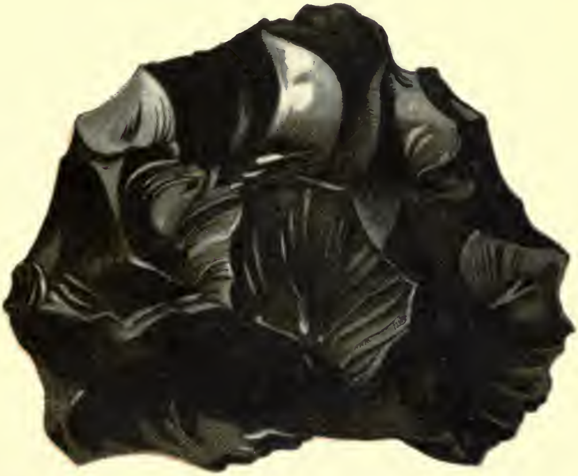

2

1, Coal. 2, Anthracite.

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